MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

JANUARY/FEBRUARY 2002

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SPECIAL ISSUE

ENERGY

Can new technology reduce our need for oil from the Middle East?

INSIDE

THE LEXUS GS 430

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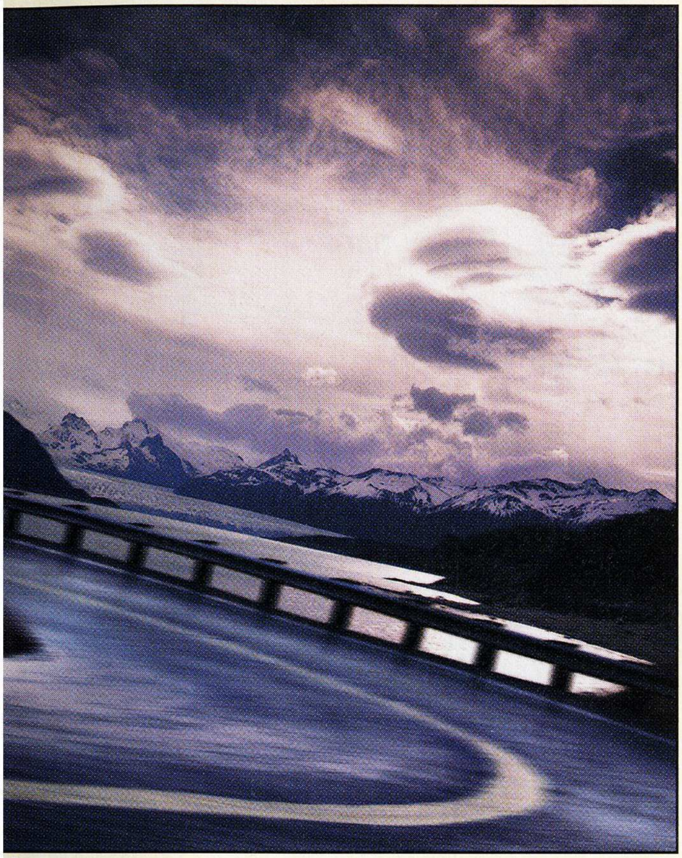

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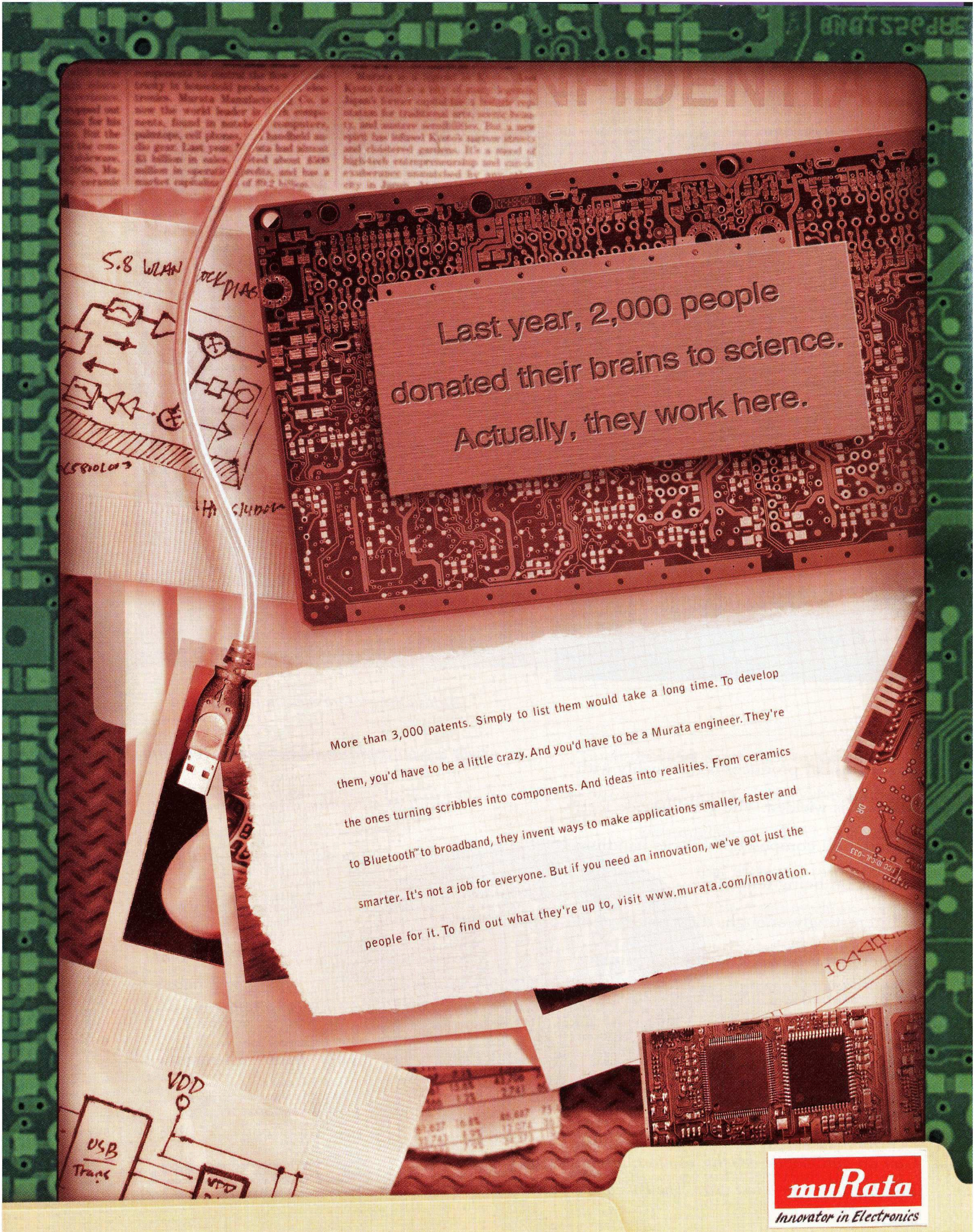

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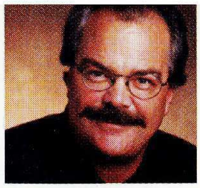


AN MIT ENTERPRISE TECHNOLOGY REVIEW

A LETTER FROM THE PUBLISHER AND CEO

R. BRUCE JOURNEY

APRIL 23, 1998, SEEMS LIKE A LIFETIME AGO. THAT SPRING we introduced a new *Technology Review* to the world. Since then the dot-com boom has imploded, the new economy come and gone and the world changed forever after September 11. All the while, we have been building a media enterprise whose mission is to promote the understanding of emerging technologies and their impact. Today we announce the formation of a new company—Technology Review, Inc.—to further that mission.

Here is what lies behind our move. In 1998 we were part of the Alumni Association of MIT, a venerable institution that had the foresight to begin publishing *Technology Review* more than one hundred years ago—in 1899. However, the board of the Alumni Association, along with Dr. Charles M. Vest, MIT's president, and other senior advisors, recognizes that to compete effectively in today's challenging media environment we need to be operationally independent from MIT.

It is a bold step. Technology Review, Inc. will be a new kind of MIT enterprise. Like MIT, it will have a deep commitment to innovation. It will be a company that takes the best attributes of the private sector—growth, productivity, efficiency, discipline, focus, aggressiveness and competitive spirit—and blends them with the innovative thoughtfulness, caring, deliberation and commitment to cause that is the hallmark of nonprofits.

Our efforts so far have yielded rich results. Between our magazine and Web site—technologyreview.com—we now reach more than 1,200,000 of the most influential readers and viewers in the world. We have hosted renowned conferences like the TR100 and Beyond Silicon. Led by Martha Connors, our VP and general manager, technologyreview.com was recently named by *PC Magazine* as one of its top 100 Web sites, and even more importantly a top 10 site in the source and reference category.

Our magazine, led by editor in chief John Benditt, has twice in the last three years been a finalist for a National Magazine Award—once for general excellence and once for best public-interest article. John is a regular on CNBC's *Marketwatch* and *Wall Street Journal Report.* We have won the Folio: Editorial Excellence Award for best consumer science and technology magazine. At the 2001 Folio: Awards, thanks to art director Eric Mongeon and his staff, we were finalists for five Ozzie Awards for magazine design—bringing home golds for best overall design, best cover and best feature design, and capturing silvers in two other categories.

As we create our new company, the 65 women and men of Technology Review, Inc., based in Cambridge, New York and San Francisco, are dedicated to building on our success by pursuing our work in accordance with a core set of values and principles. These principles mark only a starting point, the first reflection of a continuous evolution. As we do in our personal lives, we will build upon our principles in response to our experiences and changes in the world at large. But they represent core values that will always be with us. It is my pleasure to share them with you.

OUR VALUES AND PRINCIPLES

Technology Review strives to be the world's best source for understanding emerging technologies and their impact. Like our parent, MIT, we see technology as central to our culture and economic well-being. We seek to inspire, educate, stimulate and illuminate—and, with a questioning but open eye, foster a sense of wonder and fascination about the world around us.

Excellence is our standard. We aim for beautiful and thought-provoking writing and design in our magazine and Web presence, stimulating and informative conferences and events, long-lasting and mutually beneficial partnerships and the best in customer service. And we seek always to be better.

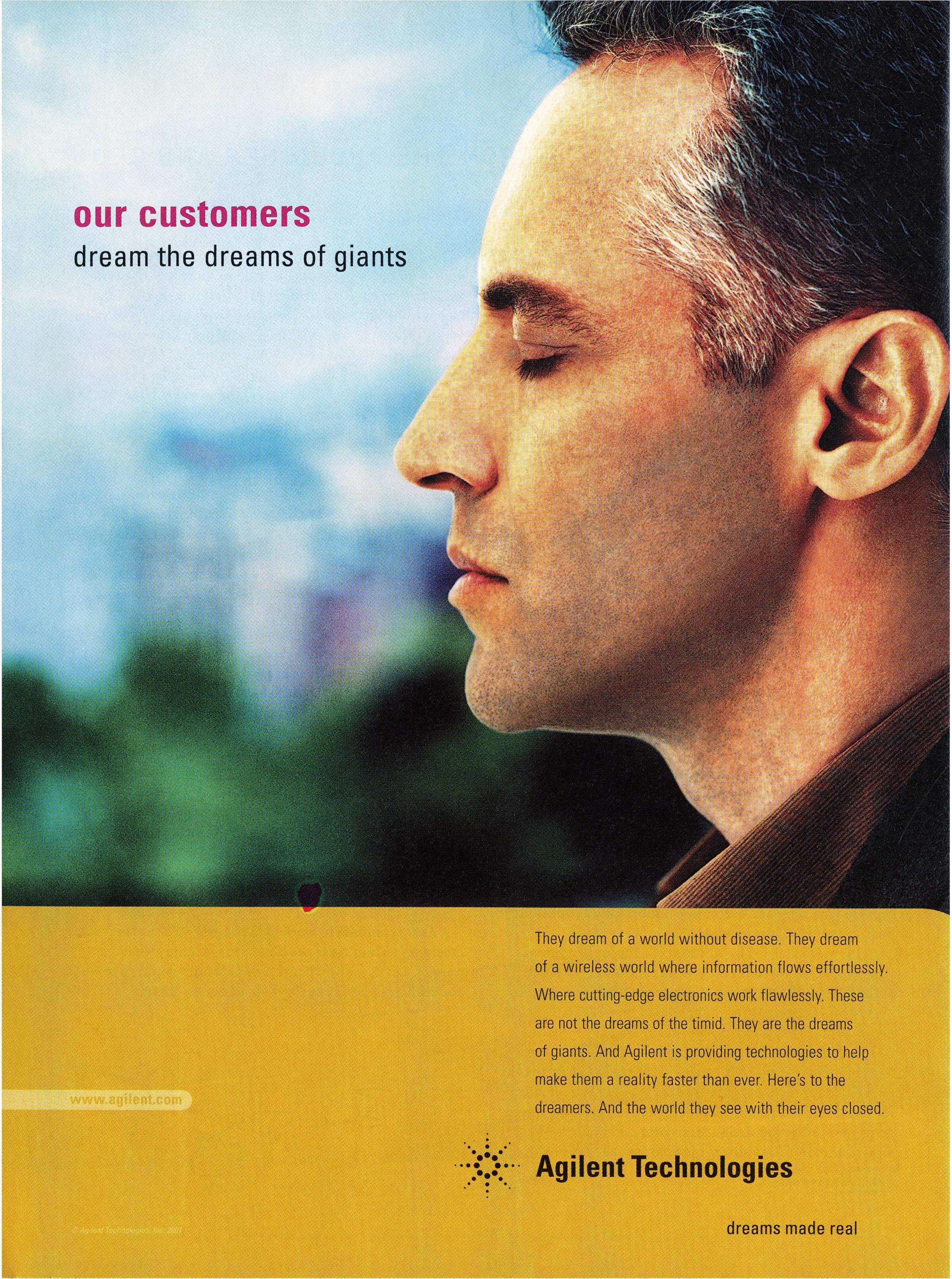
Integrity is the foundation on which we stand. We are committed to being honest, accurate and fair in what we write, in our dealings with readers, sources, advertisers, customers and visitors, and with each other. We will not compromise our integrity for any reason, financial or otherwise.

Creativity is our yardstick. We strive to foster an atmosphere where creativity can thrive and people have fun. We cherish diversity of thought and expression and see them as the basis for initiative, teamwork and personal and professional growth.

As we continue to work hard to bring you the story of emerging technologies, we hope you will enjoy what we present. Let us know what you think, and if you do like what you read, see and experience—maybe tell a friend.

Onward,

R. Bruce Journey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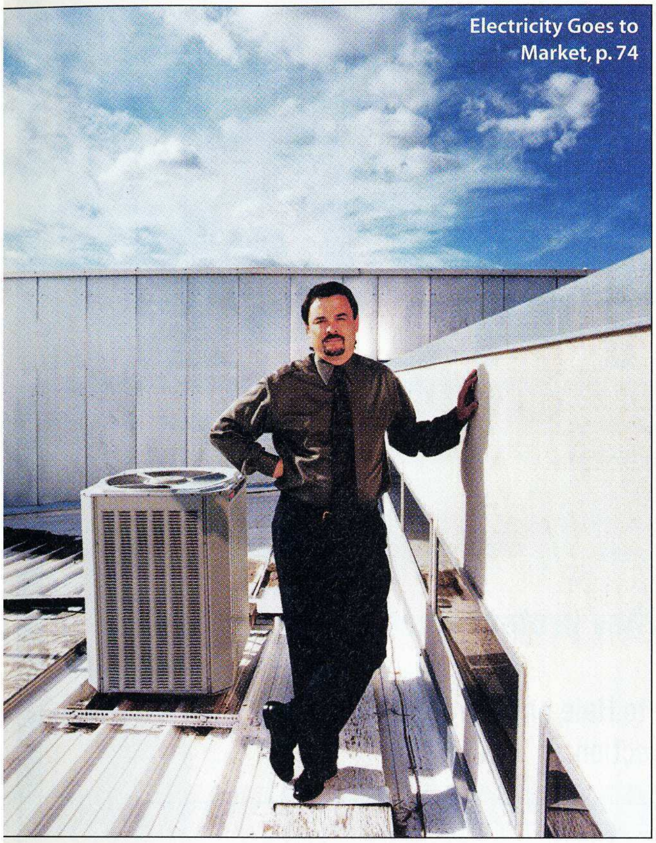

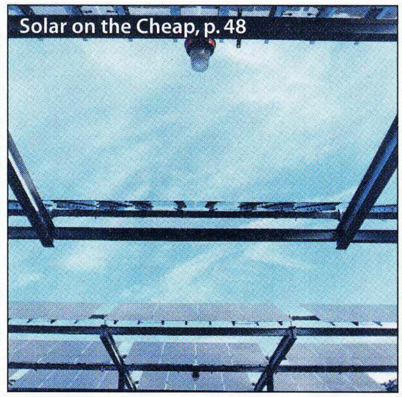

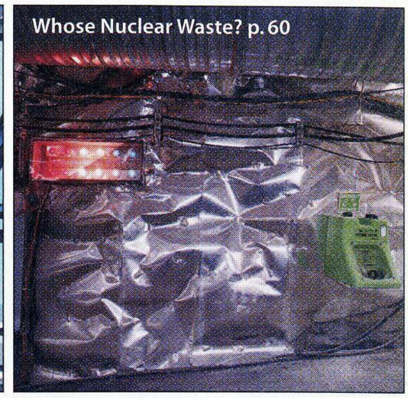

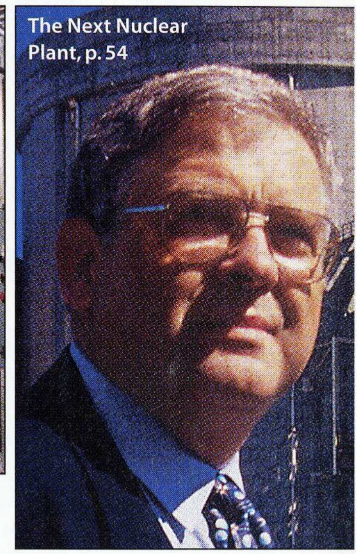

SPECIAL ISSUE: ENERGY

Coal and oil fueled the 20th century, raising living standards but imperiling the planet. *Technology Review* sizes up the alternatives that could sustain the world through this century and beyond.

COVER PHOTOGRAPH BY VITO ALUIA

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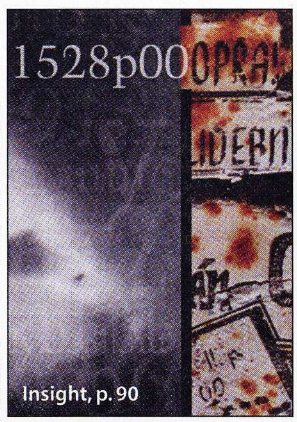
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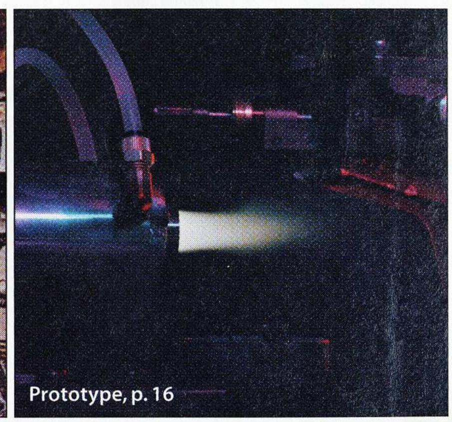
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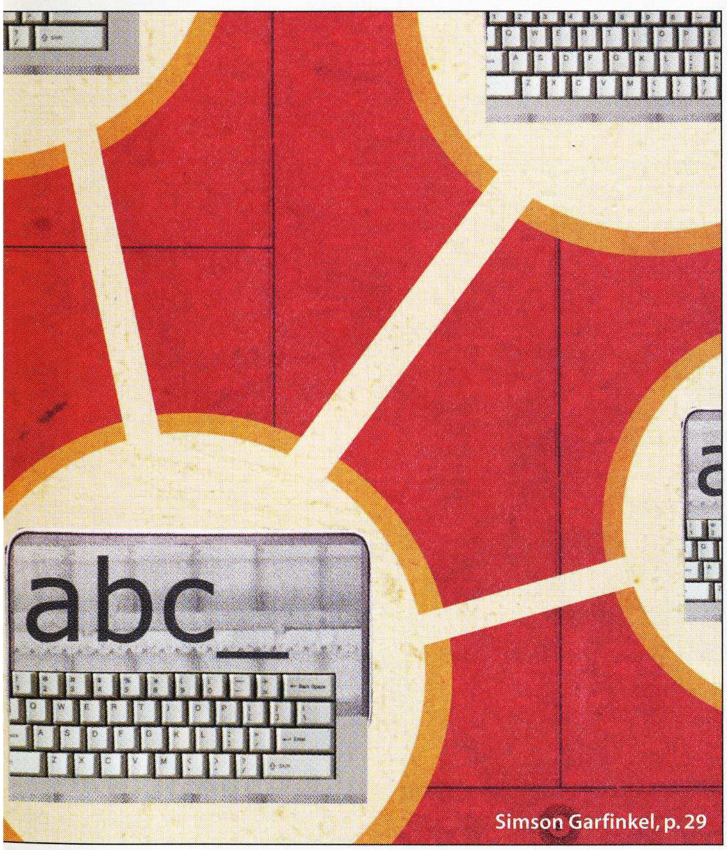

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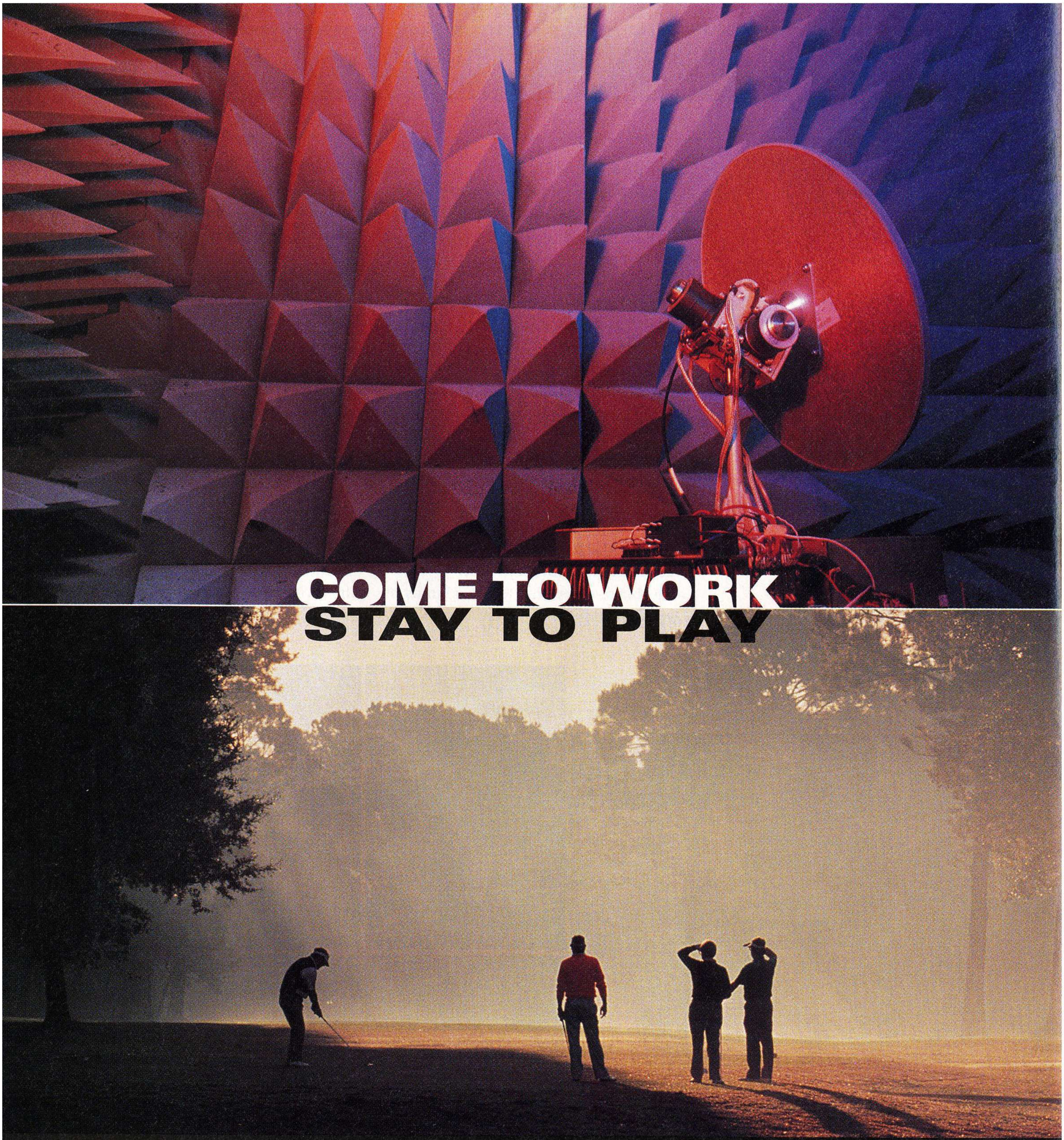
COME TO WORK
STAY TO PLAY

ENERGY FUTURES

At the beginning of the current Bush administration we heard a lot about an "energy crisis," in terms reminiscent of the 1970s. Big shortages ahead, we were told. Higher gas prices. Blackouts, brownouts. The answer, according to the administration's energy plan, which also had a somewhat retro feel to it: more. More coal, more oil, more nukes. There was only one drawback to the plan, which, like so much else that was being bruited about before September 11, seems like an echo from another era: it didn't address the two fundamental energy problems we face now and will continue to face for a long time.

The first is geopolitical. We are too heavily dependent on oil from the Persian Gulf. The chain of events leading to the horrors of September 11 runs right through the gulf region. It was, after all, to protect our supply of gulf oil that we went to war in 1990 (pieties about Kuwaiti sovereignty aside). And it was to protect that same supply that we have, since then, stationed U.S. troops in Saudi Arabia. It is the presence of those U.S. forces, in close proximity to Islamic holy sites (far more than the conflict between Israel and the Palestinians), that has inflamed the unstable temperament of Osama bin Laden and his delusional followers.

What do we need this oil for? Not for generating power. Although much of the energy picture in the United States actually does recall the 1970s, there have been some significant changes. And one of them is that we don't use much oil to make electricity. As Charles Mann tells us in the eye-opening piece that introduces this special issue of *Technology Review*, the fraction of U.S. electricity generated by burning oil has fallen from about 20 percent in 1973 to less than one percent today. So where *is* all that Persian Gulf oil going? Look no further than the tank of the SUV sitting in your neighbor's driveway. Our entire transportation system is based on refined petroleum, and although some fuels the 767s and some moves the trains and boats, most of it fuels the American love affair with the road.

That affair, which keeps us locked in the embrace of Osama bin Laden, is one problem. The other is what our consumption of energy is doing to the environment. There was a time, ten years ago or so, when it was possible to hide behind some ambiguities in the data and deny that global warming was under way. Not any more. Although the data aren't perfect—and never will be—there is almost complete consensus in the scientific community that the way we consume energy has already had an irreversible effect on the planet's climate. The only question is how hot it's going to get and what we can do to change the trend.

What can we do to fight these devilish geopolitical and environmental twins? Two steps are needed—ASAP. The first is to find a way of making the price of energy reflect its actual costs. Among the costs not factored into the price of oil, for example, are the two mentioned above: dependence on gulf oil and the devastating impact greenhouse gases have on climate. Internalizing those "externalities," as economists call them, is a very tough problem, and nobody's had much success at it, as Mann points out. But it needs to be solved.

The second critical step is to increase the amount spent on research into new technologies that can reduce our dependence on oil and also reduce the volume of greenhouse gases released into the environment. Disturbingly, even in the face of clear and present need, the amount that the United States (and most other countries, except Japan) spend on energy research has declined dramatically. The culprit here, as it is in many parts of the energy picture, is cheap oil. Cheap oil has been a great boon to our economy over the last decade or two. But it has also removed the motivation for research and development into energy alternatives. Unless we can restore it, we're headed for trouble—big trouble.

Decades of cheap oil have produced two sets of severe long-term problems: geopolitical and environmental. The solution? Finding a way to accelerate innovation in energy technology.

In this issue we explore some of the new energy technologies that might help to buy our ticket to the post-petroleum age. These articles don't by any means end our coverage of energy. Indeed, they're only a beginning. But the beginning of a new year seemed like a good time to take a step back and give you our overview of a field that will only grow in importance in the years to come: the future of energy. —*John Benditt*

THE NEW NEW MICHAEL

With this issue of *Technology Review*, we say goodbye to one columnist and welcome another. Mike Hawley joined us at the beginning of 2001 and continued some of the themes the late, lamented Michael Dertouzos laid out in his column—the primacy of human beings over technology and the significance of "soft," intangible factors in our interactions with machines. Hawley's column was a pleasure to read, and as he moves on, we thank him and wish him well. At the same time, we extend a warm welcome to Michael Schrage, whose column "In the Weeds" begins on page 19. Schrage will be looking at how, in contrast to the delicate flowers of invention, innovation must take root and spread. Schrage knows a lot about this subject, as a researcher at MIT's Media Laboratory, a consultant and the author of the book *Serious Play*, one of the best recent works on how companies innovate. I'm looking forward to hearing what he has to tell us.

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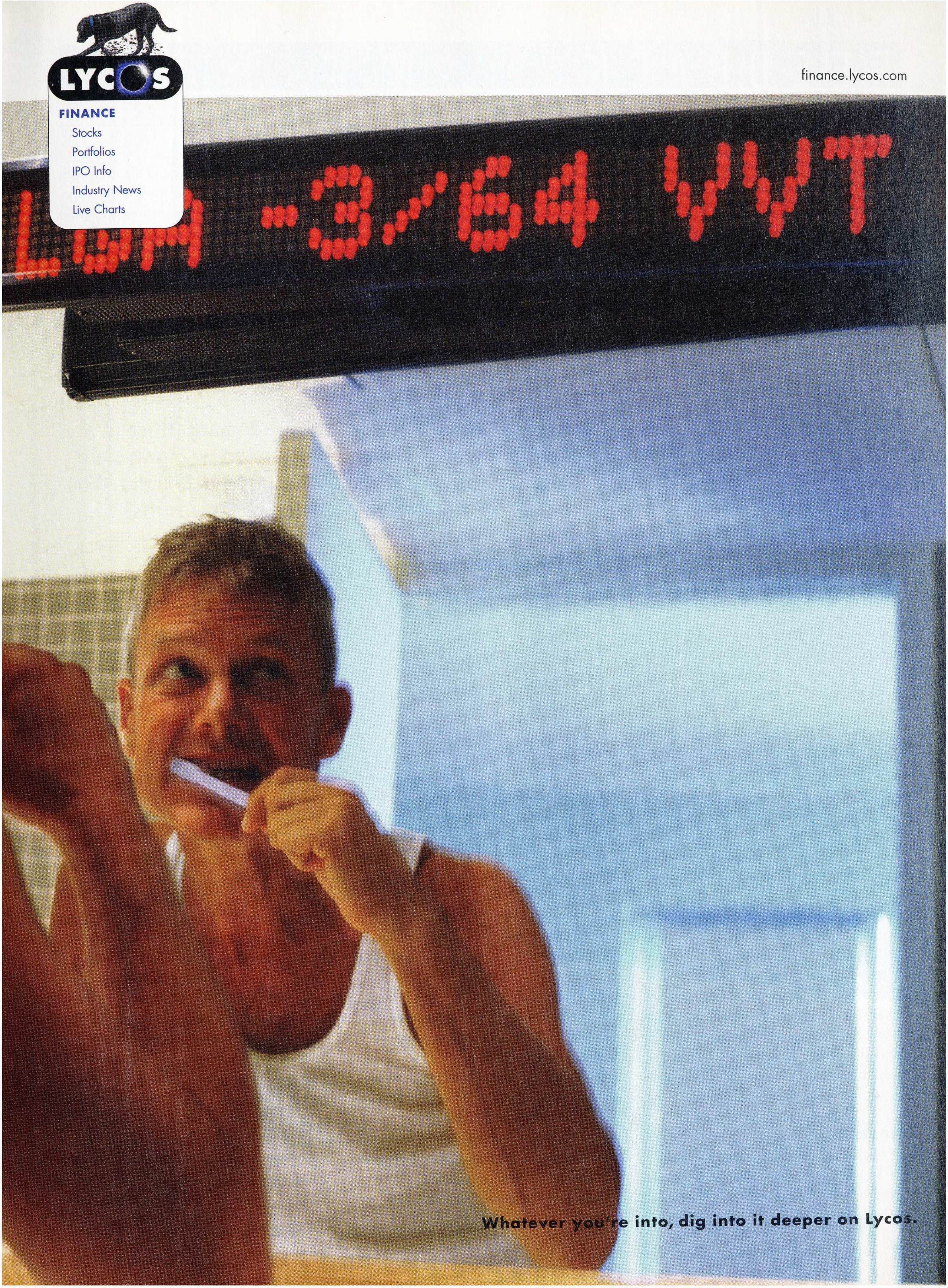
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FEEDBACK

LETTERS FROM OUR READERS

BROAD PATENTS

I would like to add to Seth Shulman's column "The Morphing Patent Problem" (*TR* November 2001) that commercial and institutional patent applications are written in as broad a fashion as possible because there are no solid ground rules for execution. Why not? There's no penalty for what might be described as "overdraft." The fault lies not in the application but in the review process. There aren't that many people in the U.S. Patent and Trademark Office who are qualified to understand the consequences of their actions. I'm not suggesting that these public servants are incompetent. They're simply overworked and outgunned by highly paid corporate or institutional legal beagles. So why should we be surprised by the results?

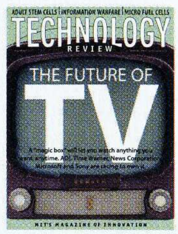
William Veon
Raleigh, NC

Seth Shulman responds:
Indeed, the fundamental asymmetry of the patent system is a big piece of the problem. There is no penalty for drawing up an absurdly broad patent application and hoping the patent examiners won't notice. Then, if the patent office does turn down some of your claims, there is nothing to stop you from relentlessly returning in an iterative process to wear the examiners down. This happens often and, as with the stem cell case, the stakes can be enormous. Maybe an "overdraft" penalty is worth considering. Or perhaps applicants could be frightened into writing their patents with a more reasonable scope by the threat of independent audits of the patent review process. Panels of independent experts in various subspecialties could regularly review the process in their fields and be given the power to rescind frivolous or overly broad patents and even fine those who abuse the system.

WEB REALITIES

Mark Frauenfelder correctly points out many of the obstacles to developing a "Semantic Web" as envisioned by Tim Berners-Lee ("A Smarter Web," *TR* November 2001). However, without the pioneering work of Marc Andreessen and Eric Bina of the University of Illinois at Urbana-Champaign, who developed the first graphical browsers in the early 1990s, Berners-Lee's World Wide Web would have remained a limited academic tool, useful only to a few computer-savvy folks. What is needed now for a "smarter" Web to become reality is for people like Andreessen and Bina to develop user interfaces that make the Semantic Web visible, pointable and clickable. Then large numbers of people will be able to explore this new Web and learn how to use it at their own pace.

Alain Vaillancourt
Montréal, Québec



"The U.S. Patent and Trademark Office is overworked and outgunned by highly paid corporate or institutional legal beagles. Why should we be surprised by the results?"

DIGITAL DIVIDE

Michael Hawley is correct that more needs to be done to bring technology to the developing world through the coordination of volunteers, and that following a Peace Corps model is one way to go ("A Technology Corps," *TR* November 2001). I was surprised, however, that his column did not mention the work of Seattle-based Digital Partners, one of the first organizations launched to bridge the digital divide. This nonprofit entity comprises a large number of information technology entrepreneurs who volunteer their time and donate money to support projects that are bringing the benefits of technology to the poor. We work with several of the organizations Hawley mentions, including the MIT Media Laboratory in India and Africa.

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THREE QUEENS

John Benditt's editorial mourning the loss of technology pundit Michael Dertouzos ("MIT in Mourning," *TR* November 2001) was touching. A long time ago, I had the privilege of meeting Professor Dertouzos. Though our encounter was brief, it had a tremendous impact on my life. At the time, I was working on a new way to make analytical and diagnostic tools for use in drug development. What I cherished most about our meeting was Dertouzos's ability to inspire and challenge me in trying out my new idea, which eventually brought me three patents, a successful company supplying lab tools for life-science research and early retirement. While I had no substantial experience in any of the "Three Queens" (information technology, biotechnology and nanotechnology), Dertouzos's wisdom made all the difference.

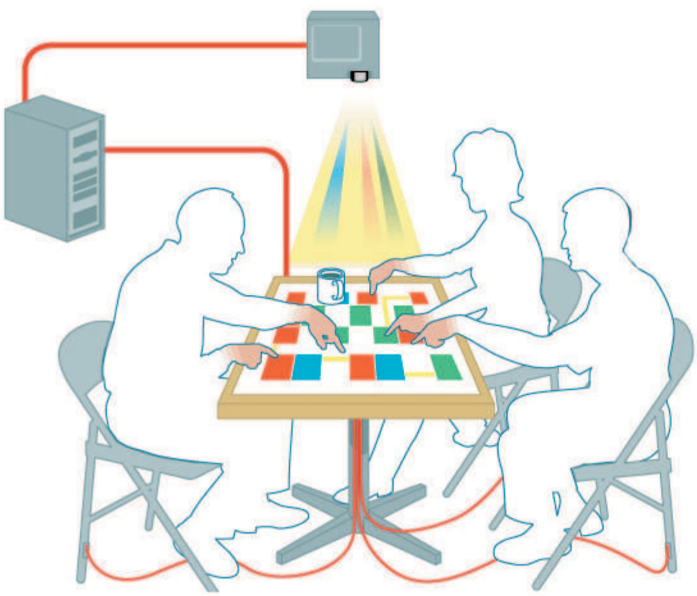
I would like to offer an annual award in Dertouzos's name for students who can demonstrate the use of the Three Queens philosophy in developing a product or service that would have an impact on technology as a whole. Perhaps *Technology Review* could help set up and manage the contest.

Roy L. Manns
Marshfield Hills, MA

SWEET POTATO

The natural sweetener in your soft drink or chocolate bar could soon come from an unlikely source: potatoes. Researchers at the University of Picardie Jules Verne in Amiens, France, have genetically modified potatoes to multiply their fructose production about 40 times. The team inserted three bacterial genes into the potato's DNA, each gene coding for a different enzyme involved in converting starch to fructose.

Most fructose is made today by adding vast quantities of enzymes to large chemical tanks of corn. But the genetically modified potatoes turn starch into fructose inside the vegetable. This makes for a much more efficient and economical process, says Rajbir Sangwan, the plant scientist who led the project. A number of food-processing companies in Europe have expressed interest in using the French technology. But Sangwan says it could be another three to five years before the potatoes are ready for the food industry.



GROUP TOUCH

Discussions around a conference table can get clumsy if participants have trouble interacting collectively with electronically displayed information. A multi-user touch screen developed at Mitsubishi Electric Research Laboratories in Cambridge, MA, may be the solution. The centerpiece is a tabletop embedded with tiny transmitting antennas. Surrounding chairs are fitted with receivers, each of which is hooked up to a central computer. An overhead projector connected to the same computer displays information across the tabletop. When a participant touches a part of the display—say, to select a button—antennas at that location send a tiny electrical signal through the person's body to his or her chair. The receiver in the chair relays the signal to the computer, triggering whatever action the participant intended. This way, the touch screen permits multiple simultaneous interactions, creating a communal electronic workspace. Mitsubishi engineer Paul Dietz expects a system on the market within two years.

WRITABLE WEB

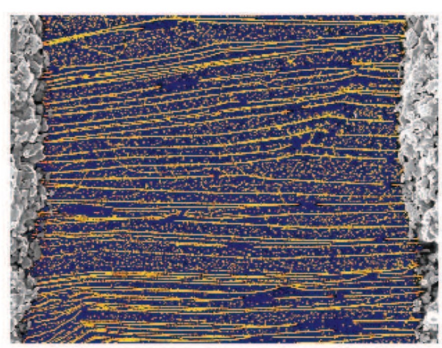
For all its power, the Web is still a one-to-many medium, with authors controlling all text that appears on their sites. But now there's a system aimed at allowing members of Web-based communities to publish information on each others' pages—making the Web as easy to write as it is to read.

Researchers led by principal scientist Eric Bier at the Xerox Palo Alto Research Center are testing Sparrow Web, a program that improves on standard Web servers by making each item on a page editable. The software provides forms where users can enter data and see it appear on the same page. PARC researchers have been using Sparrow Web for several years to manage projects, schedule events and the like. PARC is releasing an evaluation version of Sparrow Web for beta-testers and has trials under way at several technology companies and educational establishments.

FUEL CELL SAFETY

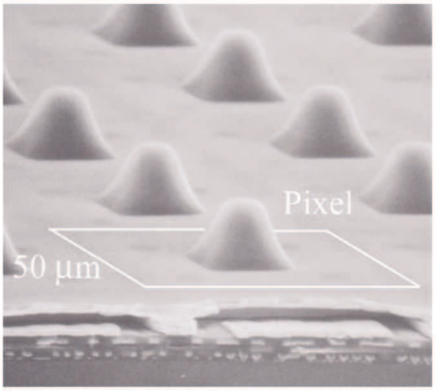
Fuel cells could provide clean power for everything from cell phones to cars. But the hydrogen that fuel cells convert into electricity is explosive. One way to improve safety: faster hydrogen sensors, which detect leaks in less than a second. A new nanoscale device created by chemists at the University of Montpellier in France and the University of California, Irvine, could fit the bill.

Like existing detectors, the nanoscale sensor uses palladium, a metal to which hydrogen molecules stick. But its tiny wires *(photo)* react thousands of times faster to the presence of hydrogen than standard detectors, says Irvine chemist Reginald Penner. The sensors also consume thousands of times less power than today's hydrogen detectors. Several companies have expressed interest in licensing the technology.



PHOTOGRAPH: ERICH WALTER, UCI CHEMISTRY; ILLUSTRATIONS: MITSUBISHI ELECTRIC RESEARCH LABS (TOUCH SCREEN); VITO ALUIA (POTATO)

FIT TO PRINT

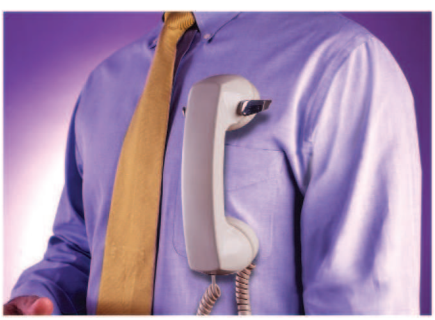


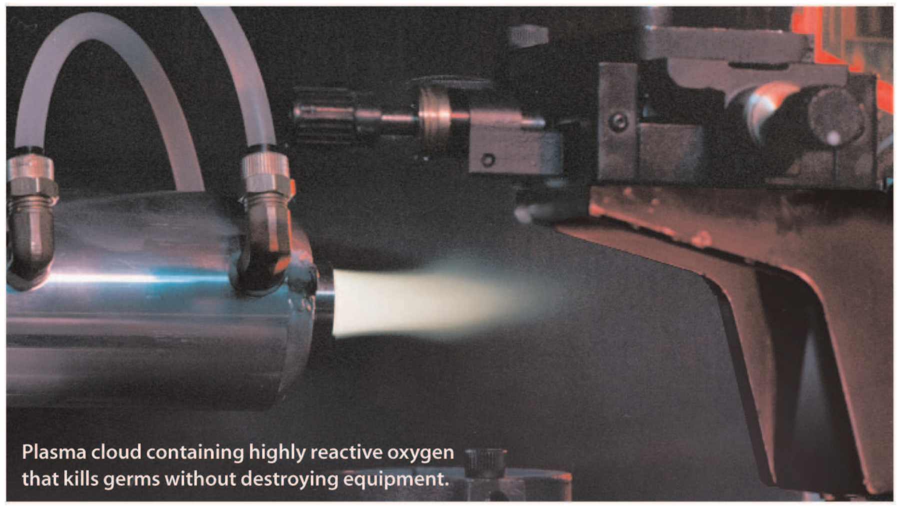
Fingerprints make terrific forensic tools or biometric identifiers—as long as they're clear. Bad prints, whether smudged by ink or by scanner, mean bad data. A team at NTT Telecommunications Energy Laboratories in Kanagawa, Japan, says it has developed a sensor that can better capture the likeness of a human fingerprint through tactile means, even if the finger is sweaty or the sensing equipment wet.

The sensor is composed of an array of circuits on a touch pad overlaid with 60,000 microscopic protrusions *(photo)*. When a finger presses the sensor, its individual ridges push down on a corresponding set of protrusions, each of which then triggers a current in an attendant electrode. Each activated circuit is translated into a pixel in a digital image of the fingertip. NTT researcher Norio Sato says that the device will enable outdoor applications such as car locks, which have been stymied by the smudge factor. The sensor is several years from availability.

VIRTUAL CHECKUP

Patients who need routine monitoring may be able to avoid visits to the doctor, thanks to a system developed at Loughborough University in Leicestershire, England. The system transmits data from any piece of medical equipment that generates an electronic signal to doctors who may be across town or across the country. Signals from electrodes on a patient's chest, for example, can be digitized, encrypted, and sent via infrared link to a cell phone for transmission through the network. Any signal can be digitized, including patient temperature or blood oxygen levels, says Loughborough electrical engineering professor Bryan Woodward. Loughborough is negotiating with various companies to miniaturize and market the monitoring system.





Plasma cloud containing highly reactive oxygen that kills germs without destroying equipment.

COLD FLAME

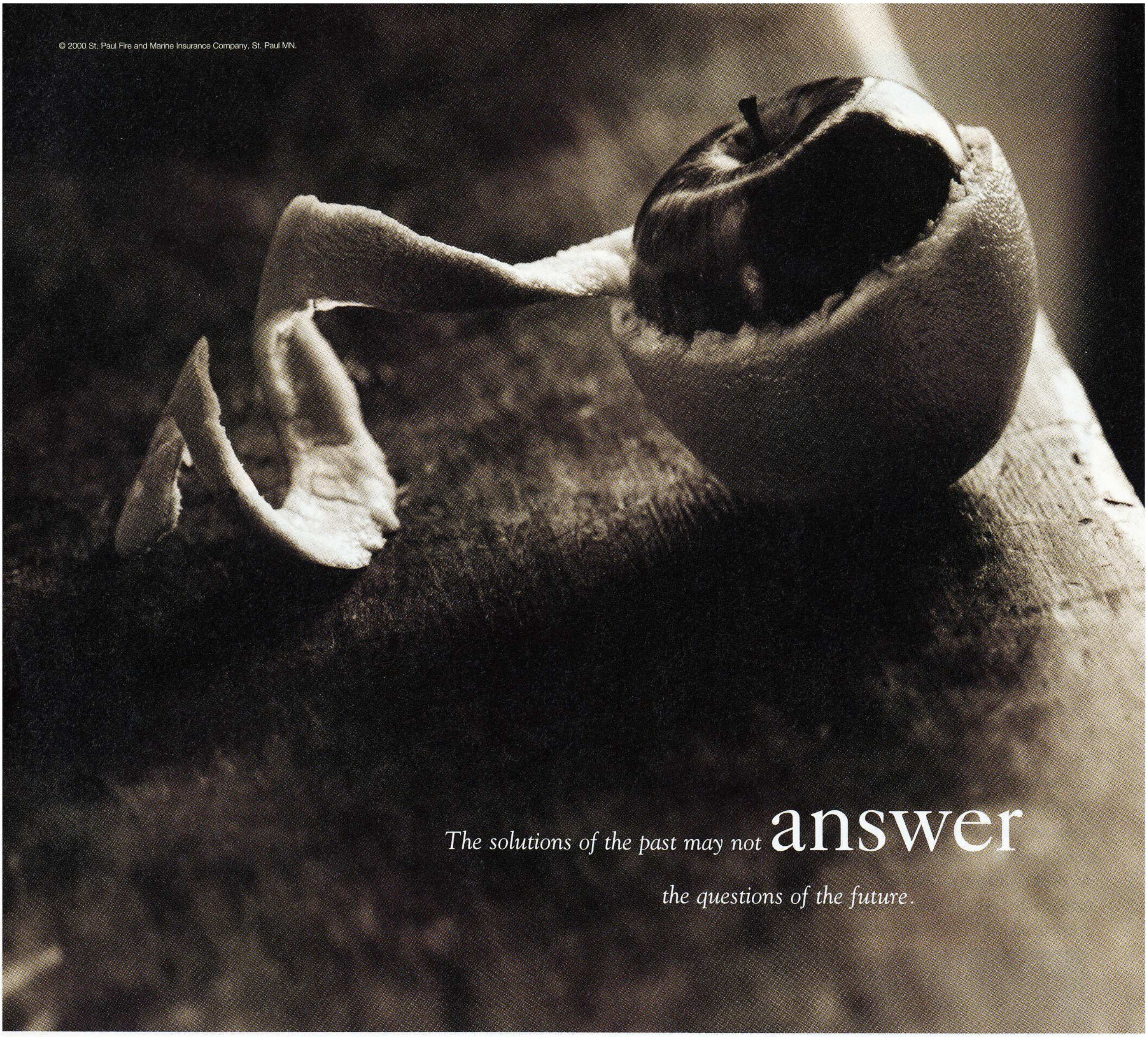
The final step in recovering from a biowarfare attack would be a cleanup of contaminated areas, but liquid cleansing agents could ruin valuable equipment, and chlorine dioxide gas can be corrosive. Now a team at the Los Alamos National Laboratory has designed an alternative dry-decontamination device. In the device, a current between two electrodes ionizes a mixture of helium and oxygen, which spews out in a cloud of charged particles—a plasma that looks like fire but that is only about 70 °C (cooler than a hair dryer's exhaust). The plasma contains a highly reactive form of oxygen that neutralizes pathogens, such as an anthrax surrogate tested by the group. "Cleaning things up without destroying them is our goal," says physicist Hans Herrmann, leader of the Los Alamos group. His group has successfully tested a two-liter decontamination chamber and is working on a chamber large enough to hold computer equipment. Herrmann has an even bigger vision: a chamber roomy enough to clean up an entire airplane.

HIGH BEAMING

In certain driving situations, high beams can improve visibility enormously. But many drivers don't bother to use them, in part because they must frequently turn them on and off. Gentex, a Zeeland, MI-based supplier of glare-reducing rear view mirrors, is trying to right this wrong. The company has begun integrating into its mirrors a pea-sized camera-on-a-chip that automates the task of turning high beams on and off. The smart camera, mounted on the windshield side of the rear view mirror, monitors and analyzes the lighting conditions on the road ahead. High beams are switched on by default, but turned off when the camera sees oncoming headlights or the taillights of a car being closely followed. Ford Motor's Lincoln division has ordered the mirrors for installation in its 2004 model cars.

Leaving high beams on (right) is safer for drivers and others.

PHOTOGRAPHS: GENTEX (HIGH BEAMING); LOS ALAMOS NATIONAL LAB (COLD FLAME); THE 2001 INTERNATIONAL ELECTRON DEVICES MEETING (PIXEL); ILLUSTRATION: VITO ALUIA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The solutions of the past may not answer
the questions of the future.

WHY WEEDS?

Even the most casual reader of *Technology Review* can't avoid coming to the obvious conclusion: there's no shortage of creative people with creative ideas. Quite the contrary, in disciplines ranging from software to biotechnology to materials science, the rate of technical change has accelerated far more rapidly than the ability of most markets to successfully absorb it.

The problem isn't figuring out how to get people to become more "innovative"; it's figuring out how to get people to accept and apply innovations more productively. The glut of new ideas has paradoxically created a critical shortage of the human ingredients that determine just how quickly and cost effectively they get used.

So instead of celebrating the "heroic brilliance" of innovators, this column will explore innovation from a different and more important perspective. After all, it is customers and clients—*not* innovators—who determine how great ideas become successful innovations. In fact, one could make the argument that customers—especially the so-called early adopters—are the true innovators in the development process.

WEBB CHAPPELL

As Bob Metcalfe, Ethernet inventor and founder of 3Com, observed in an inciteful/insightful essay for this magazine: "Invention is a flower, innovation is a weed" *(*TR *November/December 1999)*. That is, an original idea can be brilliant, profound and compelling—but what ultimately gives it power and influence is that it spreads. Great ideas aren't enough; they have to be adoptable and adaptable. They have to thrive outside the nurturing greenhouse and the loving gardener's care.

Designing for adaptability, adoptability and diffusion is a black art. However, it's a black art whose magic matters more and more in an era where choice is the rule and not the exception. The more choices you have, the more your values matter. The Microsofts, Mercks and BMWs have become as concerned about how best to package their "new&improvedware" as they are with the innovations themselves. Ironically, technology is annihilating the distinctions between the innovation and how it gets packaged and sold. The "breakthrough" is no longer in the idea itself; it's in how the idea gets adopted. If it's not adopted, it's just another good idea.

Take, for example, the handwriting recognition software developed by Apple Computer for its handheld Newton personal digital assistant in the early 1990s. On a technical level, it was far more innovative than the Graffiti interface software used by nascent Palm. But it turned out that millions of people were willing to learn how to "write" in Graffiti via the cleverly designed interactive tutorial, while few people had the patience to wait for the Newton's buggier handwriting recognition software to learn how to recognize their scribblings.

To be sure, the Palm's one-button, one-touch PC synchronization interface played a big part in its popularity. But the fact remains that the less innovative technical solution that made more demands on the user became the undisputed market leader. Handwriting recognition software, so ardently championed by Apple, still languishes in technical limbo and marketing disrepute.

The point is that there is a complex ecology of innovation that requires aspiring entrepreneurs and established institutions to rethink what it means to bring ideas to markets. Sometimes—particularly during innovation gluts—it might be smarter to bring markets to ideas. "Most engineers don't understand that selling matters," Metcalfe wrote in his essay. "They think that on the food chain of life, salespeople are below green slime. They don't understand that nothing happens until *something gets sold*."

May I respectfully disagree? How about, nothing happens until *something gets bought*? As successful innovators know, how innovations get sold often has absolutely nothing to do with

The problem isn't figuring out how to get people to become more "innovative"; it's figuring out how to get people to accept and apply innovations more productively.

how they actually get bought. Just as importantly, how innovations get bought often has nothing to do with how they actually get used. These aren't subtle distinctions or semantic games; these are the make-or-break factors that determine whether a brilliant idea is a solitary beautiful flower or a ubiquitous weed.

Not to worry—this will not be a column about "marketing" innovation. "Marketing" doesn't come close to capturing the underlying dynamic and dialogue as innovators and customers experiment with beta software or brave new materials in order to get them to work. We need to recognize that the story of how a customer works with a new idea is every bit as dramatic and important as the story of how the innovator first came up with it.

"In the Weeds"—drawing from an array of both happy and hysterically tragic case studies—will explore and explain what innovation means from this counterintuitive perspective. How do innovations mutate and evolve to become more adoptable and adaptable? How might the epidemiology of innovation yield insights into better design for diffusion? Is survivability of an innovation overwhelmingly a matter of luck and timing or something else?

There are good answers to these questions. The goal of this column will be to find them, poke them and prod them into usefulness. Why? Because we need more innovative ideas about how to manage innovative ideas. Enough with the flowers; it's time for the weeds. TR

WEB TOLLS AHEAD?

Core software may no longer be free

The real force behind the Web, many software developers argue, is that it's free. What makes the Web truly worldwide, after all, is its interoperability—you can call up virtually any Web page on virtually any device connected to the Internet—and that depends on free software. But now members of the World Wide Web Consortium, the MIT-based industry forum devoted to promoting interoperability, are locked in a debate with outside critics over whether the royalty-free tradition can continue in a world where many companies hold patents on—and would like to start profiting from—the software needed as the backbone for next-generation Web standards.

Last August, the consortium's Patent Policy Working Group proposed a set of procedure changes that would, for the first time in the consortium's history, create an official structure for companies to collect licensing fees on technologies incorporated into Web standards. Such fees would typically be paid by companies that sell commercial software or services based on the standards, but they could be passed along to the average Web user in the form of higher prices or usage charges. The working group said the policy was needed to encourage companies to disclose relevant patents early in the standards-making process. But so many outraged e-mails poured in from software developers concerned about the policy's implications for the openness of the Web that the working group had to extend the period for public comment.

Now the group is working to find a compromise that will give patent holders incentives to participate in the standards-making process while also appeasing independent developers and open-source-software advocates, whose faith in the World Wide Web Consortium is crucial to the adoption of its standards. "I can't think of any more fundamental question that I've seen in my time at W3C," says Daniel J. Weitzner, director of the consortium's Technology and Society domain and chair of the working group.

From the Web's beginnings in the early 1990s, the designers of basic standards such as the hypertext transfer protocol, which manages communication between the servers where Web pages are stored and the browsers where they're displayed, have declined to patent or collect royalties on their underlying code—freeing developers of newer Web technologies from fear of legal trouble or burdensome fees. The tradition continued within the World Wide Web Consortium, whose working groups develop and recommend common Web standards that cover areas such as privacy, accessibility and streaming multimedia. The groups have never had a formal policy requiring members to provide royalty-free access to patented technologies that get built into those standards, relying instead on custom.

But that custom began to break down about three years ago, just before the consortium was set to release a final draft of its system for standardizing the way browsers exchange and display information about various Web sites' privacy practices. In January 1999, the Seattle software company Intermind (now called OneName) told the consortium that it had won a patent covering the same technological ground and proposed collecting a one percent royalty from developers who implemented the privacy software in commercial products such as browsers. The consortium eventually concluded that Intermind's patent did not overlap with the new privacy standard, but it lost nearly a year in the process. The experience left its members determined to do something to avoid future patent obstacles.

Under the framework proposed last August by Weitzner's group, companies that belong to the consortium must disclose up-front all patents relevant to standards being developed by the working groups. But that's not all: participants who submit patented technologies for inclusion in common standards must also commit to granting a license on those patents, on either royalty-free or "reasonable and nondiscriminatory" terms.

FREDRIK BRODEN

(Under the latter terms, which are commonly written into standards for other technologies such as wireless communications, patent holders must offer licenses to all implementers worldwide for a reasonable fee.) The consortium received more than 2,400 public comments on the policy, the majority opposing the introduction of fee-based licensing.

The policy would have a major practical impact on the evolution of emerging standards such as VoiceXML, which is intended to allow hands-free, eyes-free access to the Web via telephones and other devices. Some companies that hold patents on technologies being considered for inclusion in the VoiceXML standard have offered them on a royalty-free basis, says Weitzner, but others have offered them only on a reasonable and nondiscriminatory basis. "That's a place where we're going to have to make a decision: is it okay for VoiceXML to require a license fee, or should we try to do a royalty-free standard there?"

The consortium does need some kind of policy to help it through the increasingly dense minefield of Web-related patents, acknowledges Steven Champeon of the Web Standards Project, a group that lobbies browser makers to provide uniform support for the World Wide Web Consortium's standards. But gaining patent holders' cooperation by allowing them to charge royalties on certain technologies is a slippery slope that could lead to a pay-as-you-go Web, he warns. "It's perfectly possible for the W3C to adopt a policy that requires their members to disclose any patent, but there's no reason why they must adopt both the defensive patent disclosure policy and the ill-considered [fee-based] scheme at the same time," Champeon says.

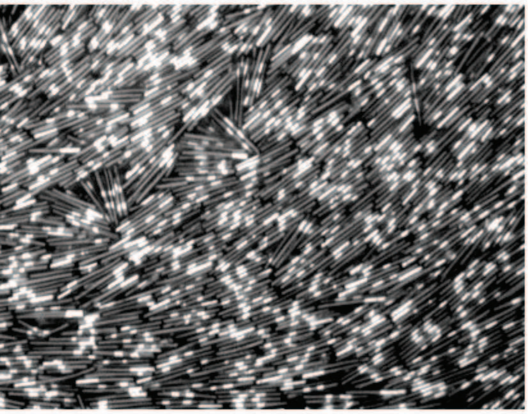
"I can't think of any more fundamental question that I've seen during my time at W3C," says Daniel J. Weitzner, chair of the consortium's Patent Policy Working Group.

Other critics say any kind of fee-based licensing is incompatible with the historically open nature of the Web. "The very best work is going to be done by people who are engaged in learning—who pick up the best stuff there is and make it a little better—and not by companies who are inventing proprietary and closed software," says Eben Moglen, a Columbia Law School professor and general counsel for the Free Software Foundation who recently joined the working group as an invited expert.

But advocates of the draft policy such as IBM, which also has a representative on the working group, say that some of today's most promising Web technologies are coming from the private sector, and that uncertainty over patents is discouraging full corporate participation in the standards process. "This [licensing] approach encourages participants to contribute more of their patented technology, resulting in the adoption of the best technical solutions," said Gerald Lane, IBM's program director of corporate standards practices, in a public comment.

Other high-tech leaders argue that royalties on Web software are needed because developers, like everyone else, like to be paid for their work. "People want personalized content, anywhere, on demand, and a lot of technology is required to do that," says Michael Miron, CEO of ContentGuard, a company that licenses digital rights management systems. "But if there is no remuneration for R&D, the only people who would enter this market are fabulously wealthy people or hermits who have no need of income."

Stakeholders will soon have another opportunity to comment on the policy, a new draft of which is due sometime this spring. Weitzner says the draft will respond to many of the concerns raised by critics. "The level of anger and concern seemed to come out of people's sense that W3C is important to them," he says, "and we are going to do everything we can to maintain that trust." —*Wade Roush*



Stripes of silver on SurroMed's nanobarcodes glow more brightly than adjacent gold stripes.

BAR-CODING LIFE
Tiny tags to decode disease

BIOTECH | Bar codes have revolutionized how everyone from warehouse managers to pharmacists keeps track of items. Mountain View, CA-based SurroMed is using them to help biologists track genes, proteins and other molecules. SurroMed's microscopic bar codes could eventually be used to identify and quantify thousands of different molecules in a sample of a fluid like blood, making biological and medical tests far more informative.

SurroMed's "nanobarcodes" work much like conventional bar codes, except they are microscopic rods, striped with bands of gold, silver and other metals. Varying the width, number and order of the stripes could generate thousands, if not hundreds of thousands, of unique identifiers, says SurroMed CEO Gordon Ringold. The rods could be attached to probes that bind to specific biological molecules, forming bar-coded tags.

The problem with existing fluorescent tags, which are the workhorses in many of today's biological tests, is that they only let researchers analyze a few different types of molecules at a time. With nanobarcodes, though, thousands of different tags could be added to a biological sample at once. A sample-reading device would then snap a microscopic image, and a computer would identify all the tagged molecules in the image by the nanobarcodes attached to them.

"This is like miniature supermarket technology," says Chad Mirkin, director of the Institute for Nanotechnology at Northwestern University. "Conceptually, this is a major advance" in biological analysis, he adds. SurroMed hopes its nanobarcodes will help researchers identify patterns of perhaps hundreds of molecules that form molecular signatures for different diseases, and for different stages of illness and recovery. More complete knowledge of the molecules involved in disease could help researchers develop better drugs and could form the basis for highly specific diagnostic tests.

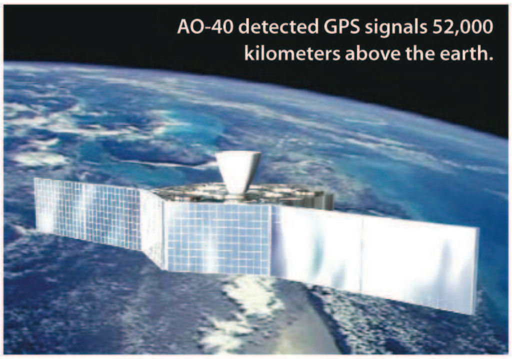
In preliminary studies, the company is using nanobarcodes to identify molecular signatures in diabetics' blood, Alzheimer's patients' brain fluid and other biological samples. According to chief technical officer Michael Natan, the first commercial nanobarcodes for research could be available in the next couple of years. —*Alexandra Stikeman*

GPS IN SPACE

SPACE | The Global Positioning System has helped many people find their way on earth. Now, this network of satellites may help fellow satellites find their way in space, and keep orbiting communications devices from colliding.

The conventional way to keep satellites on course involves controllers on the ground who monitor any changes in the satellites' orbits using radar, for example, or radio transmissions. In recent years, however, several low-flying satellites (just a few hundred kilometers above the earth) have carried GPS receivers that allow them to determine their positions instantly and adjust their orbits faster and less expensively than if ground controllers had to intervene. But until now nobody knew if the GPS system would work *above* its own network of satellites, which orbit at 20,000 kilometers. This is an important question, since some 300 communications satellites already reside at 36,000 kilometers, the altitude at which a device can achieve "geosynchronous orbit," hovering over the same part of the earth at all times.

In September, the amateur satellite AO-40, in cooperation with NASA, successfully detected a GPS signal at an altitude of 52,000 kilometers. Because GPS satellites only beam their transmissions toward the earth, AO-40 had to rely on small portions of beams that made it past the earth from satellites on the other side of the planet, up to 70,000 kilometers away.

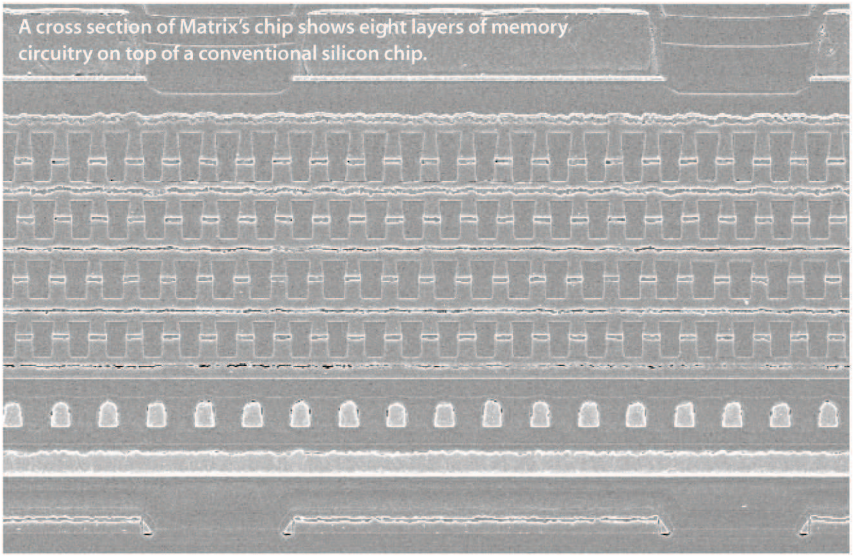


AO-40 detected GPS signals 52,000 kilometers above the earth.

"This capability can revolutionize the way we fly satellites in the future," says Frank Bauer of the Guidance, Navigation and Control Center at NASA's Goddard Space Flight Center in Greenbelt, MD, who arranged for the experiment. "We will be able to autonomously control spacecraft and keep them in the right orbit." That ability may open up geosynchronous orbit to more satellites. The number of new devices the orbit can accommodate is rapidly dwindling, because the satellites must be widely spaced to avoid collisions. Bauer believes that satellites using GPS navigation could be safely placed closer together. This could help meet the growing demand for satellite communications services in areas like North America, Europe and East Asia, where space for satellites is shrinking the fastest.

Eventually, GPS could prove itself at even higher heights. San Diego-based TransOrbital plans to include a GPS experiment on TrailBlazer, an unmanned commercial lunar mission scheduled for launch in mid-2002. That experiment will test the ability to use GPS signals for navigation as far away as the moon, about 385,000 kilometers away. —*Jeff Foust*

ILLUSTRATION COURTESY OF AMSAT; PHOTOGRAPH COURTESY OF SURROMED


A cross section of Matrix's chip shows eight layers of memory circuitry on top of a conventional silicon chip.

CHIPS GO 3-D

HARDWARE | It's an axiom in real estate: when land gets expensive, build up. For 30 years, chip designers have considered whether building integrated circuits with multiple layers might create cheaper, more powerful chips. Previous attempts to build such three-dimensional chips have failed or proved too expensive, but Santa Clara, CA-based startup Matrix Semiconductor plans to bring the first one to market in just a few months. While Matrix's techniques won't likely result in more computing power, they will produce cheaper chips for certain applications, like memory.

Matrix has adapted technology developed for making flat-panel liquid-crystal displays to build chips with multiple layers of circuitry. The company—founded in 1997 by Stanford University electrical engineer Tom Lee, Mike Farmwald, cofounder of chip connection technology company Rambus, and others—starts with a standard silicon chip. It paves the chip with glass, adds a new layer of silicon on top and starts the process over again. Matrix connects the layers by etching holes through the glass and filling them with silicon. So far, the company has built chips with eight layers on top of the base chip, and it believes it can go higher.

Matrix's first products will be memory chips for consumer electronics like digital cameras and audio players. Current flash memory cards for such devices are rewritable but expensive; Matrix's chips will cost ten times less, about as much as an audiotape or a roll of film, but will only record information once, says Dan Steere, Matrix's chief marketing officer. The cost is so low largely because the stacked chips contain the same amount of circuitry as flash cards but use a much smaller area of the extremely expensive silicon wafers that form the bases for all silicon chips. The chips will also offer a permanent record of the images and sounds users record.

The amount of computing power the company can ultimately build into its chips could be limited, though. "You may never build a supercomputer out of this," Lee says, "but we've got an awful lot of room to grow." He hopes to eventually build chips for cell phones, or low-performance microprocessors like those found in appliances; such chips would be about one-tenth as expensive as current ones.

Most other teams working on three-dimensional chips, including groups at MIT, IBM, Rensselaer Polytechnic Institute and SUNY Albany, are betting on techniques for bonding conventional chips together to form multiple layers. Whichever approach ultimately wins out, though, multilayer-chip-building technology "opens up a whole new world of design," says MIT electrical engineer L. Rafael Reif. And like a city skyline transformed by skyscrapers, the world of chips may never look the same. —*Erika Jonietz*

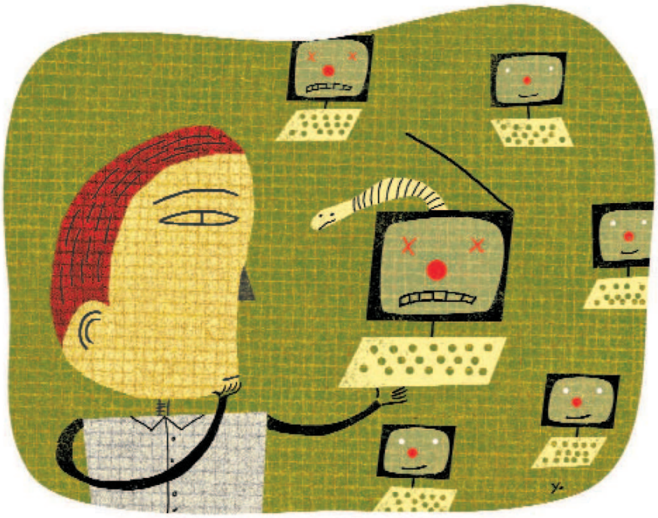
ILLUSTRATION: JAMES YANG; PHOTOGRAPH COURTESY OF MATRIX

DELIVERING DSL

BROADBAND | **Digital subscriber lines, or DSL, take advantage of telephone system infrastructure to give consumers broadband Internet access. But the service's availability is notoriously limited to certain neighborhoods. There may soon be help for the DSL-deprived, however: a new version of the technology nearly doubles its reach.**

With conventional DSL, a device in a central switching facility connects a phone line to the Internet backbone, then uses high-frequency signals to communicate over that line with a DSL modem in the home. But if your home is one of the millions that's more than five kilometers from such a facility—as the wire wanders, not as the crow flies—you're out of luck; the signal degrades before it reaches you. The new DSL service, called G.SHDSL, combines a lower-frequency signal with software that reduces transmission errors to send the signal almost twice as far. Amplifiers on the line also help push the signal along, says Mark Peden, a board member for an industry consortium aimed at making DSL a mass-market technology.

The new DSL offers another advantage: it sends data as fast as it receives it, in contrast to most current residential systems, which limit upload speeds and cause problems if you're, say, using video-chatting software. Better yet, the technology is ready for deployment: a number of firms, including Cisco Systems, already offer complete systems. "Europe will probably adopt G.SHDSL within a year," says Ernie Bergstrom, a senior analyst at Cahners In-Stat Group in Scottsdale, AZ. "It will probably show up in the United States about a year later." The lucky few who already have broadband access, in other words, might soon have plenty of company. —*Mike May*



WORM WATCHERS
Simulation tools fight new network parasites

SOFTWARE | Most people now know the drill when it comes to thwarting a computer virus. Receive an e-mail with a vague subject line? Trash it.

If only that were enough to keep the Internet free from the wanton devastation of Code Red II and Nimda, just two of the new automated menaces (both technically worms, rather than viruses) now infecting millions of computer networks. Security experts admit such attacks can't be prevented entirely, but they say simulation technologies now in development might at least help network operators predict how their systems will respond to invaders, so they can prepare better defenses and contain the damage.

The latest rashes of corrupting code are particularly virulent because they don't require any social engineering—a phrase used to describe how virus makers trick people into opening tainted e-mails—and can infect networks without anybody noticing. Code Red II scans the Internet for vulnerable Web servers and creates "back doors" that allow hackers to control the servers remotely, to date causing $2 billion worth of server downtime and Internet traffic jams. Nimda spreads automatically via shared files, Web pages, e-mail and other routes. Infected computers can be cleaned, but the worms spread with such speed and in such volume that networks can grind to a halt.

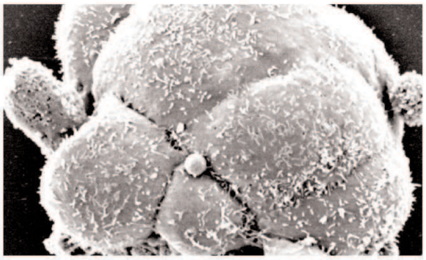
Security experts are working to remedy individual vulnerabilities, but they agree the virus makers will always be able to find new ways to intrude. "It's no longer a question of 'How can we keep them from coming in?' but 'What do we do now?'" says computer scientist David Fisher at the CERT Coordination Center, a government-funded research and development center for Internet security at Carnegie Mellon University. Fisher helped develop Easel, a software simulation tool that runs potential nightmare scenarios involving the likes of Code Red and Nimda. Using the collected data from previous attacks—how many servers were affected in what span of time, for instance—it creates reference models that computer security specialists can use to minimize damage in future attacks. They might, for example, configure a network to recognize a nascent infection and shut down affected servers before the virus can spread further.

The center recently released the beta version of Easel, and similar software is under development at companies such as McAfee and Symantec. "We can't hope to stop them," says Sam Curry, virus expert at McAfee, "but by knowing what might happen when they do hit, we can at least keep them contained." —*Kevin Hogan*

GROWTH INDUSTRY

BIOTECH | **Adult stem cells, found in the liver, bone marrow and elsewhere, are the biological workhorses that repair injuries and form new tissue. Researchers hope to use them to cure Alzheimer's disease, say, or grow new livers; but the large numbers of cells such treatments would require can't reasonably be harvested from human donors—and many types of adult stem cells are difficult to mass-produce in culture. MIT bioengineer James Sherley may have found a way around that difficulty, potentially overcoming a huge barrier to putting adult stem cells to medical use.**

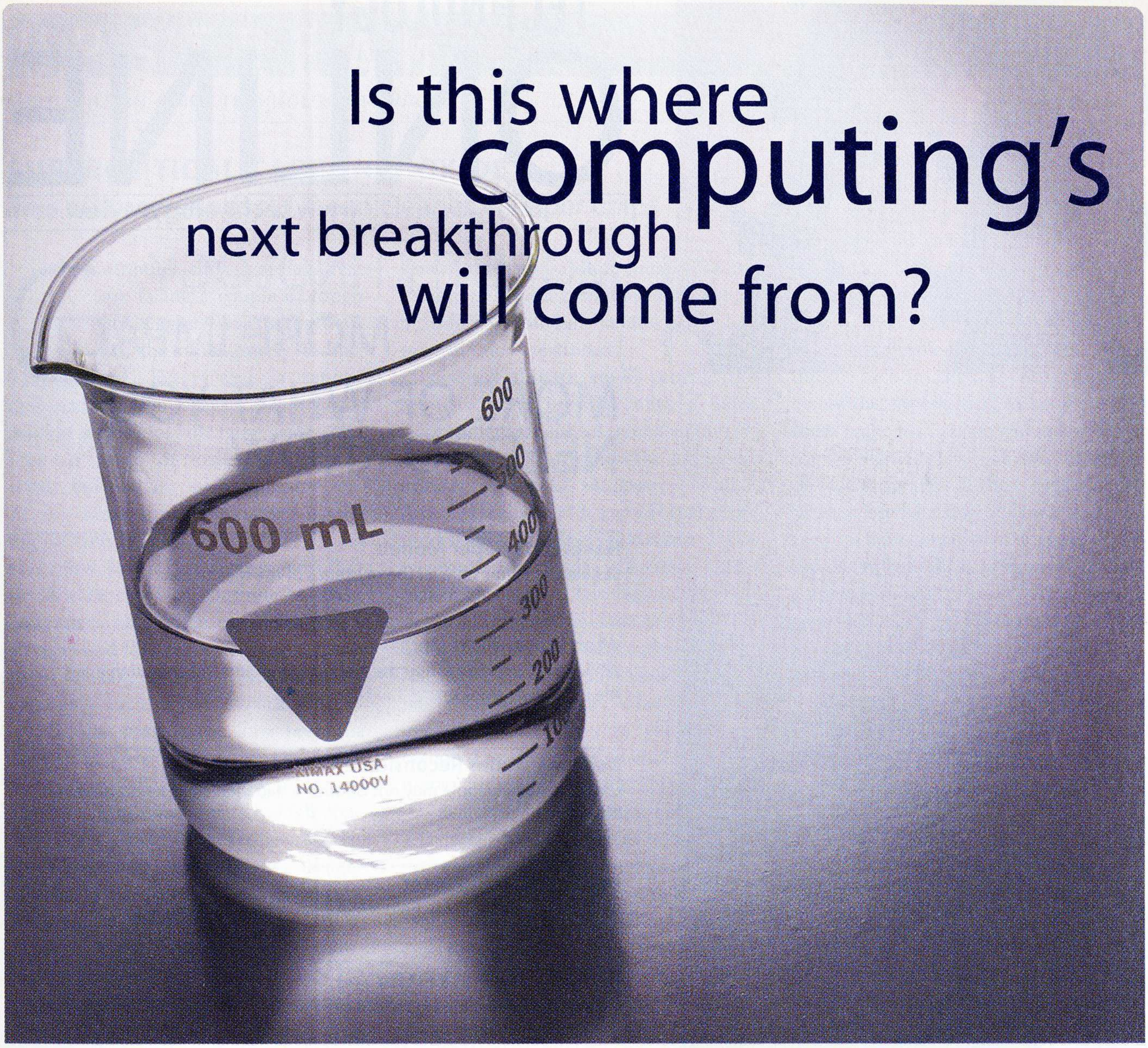
Sherley's group has found a chemical that allows adult stem cells—at least those from rat livers—to multiply in culture indefinitely until it is removed. If Sherley's approach pans out for human adult stem cells, researchers and doctors could finally have a way of generating enough cells to repair damaged organs and tissues. "If you can grow these things," says Yale University stem cell biologist Diane Krause, "maybe we'll be able to inject them and get them to work [inside the body]."



Rat liver stem cells growing in culture.

Sherley is looking to see whether the chemical or a related compound will work as well with human adult stem cells. Even limited success in these experiments could have a big medical impact, says Michael Ehrenreich, president of New York-based health-care investment firm Techvest. Just extending the technique to human liver cells, for instance, could hasten the development of external devices that use living cells to aid patients with liver failure. And Ehrenreich and stem cell researchers agree that the work holds out hope for the ability to grow all kinds of adult stem cells in the future. If they're right, it would go a long way to helping adult stem cells make the transition from laboratory curiosity to real-world medicine. —*Erika Jonietz*

PHOTOGRAPH COURTESY OF KATHRYN E. WACK, MIT; ILLUSTRATION: JAMES YANG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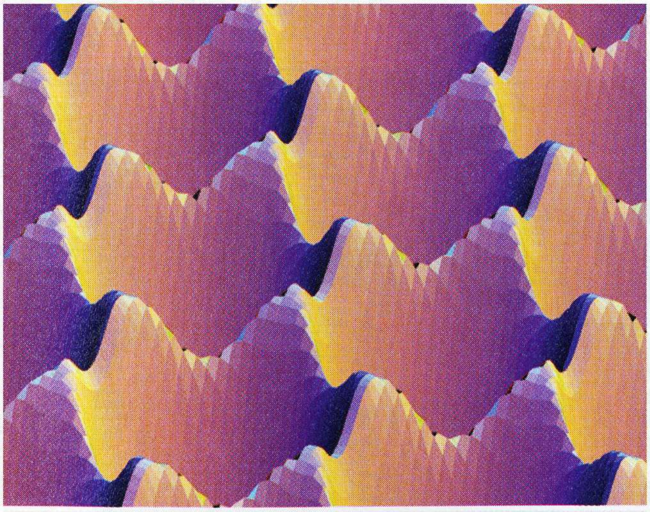

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SUPERCRITICAL CARBON DIOXIDE

This odd solvent could mean cleaner, cheaper chips

Computer chip manufacturers are facing a couple of tough challenges: one environmental, the other purely technical. Every year, a typical chip-making plant sucks up about four million gallons of ultrapure water and uses an ocean of toxic chemicals to scrub and prepare microchips for use. At the same time, companies in the highly competitive industry are trying to further shrink transistors and other devices on chips to continue to make computers and other microelectronics cheaper and faster. The solution to both these challenges could come from an unlikely source: carbon dioxide.

Carbon dioxide has long been the nemesis of environmentalists because of its role in global warming, but under just the right conditions—namely, high pressure and the right temperature—it's one of nature's best and most environmentally benign solvents. Decaf-coffee lovers, for instance, benefit from its ability to remove caffeine from coffee beans. During the last few years, carbon dioxide has also made inroads in the dry-cleaning industry, providing a safe cleaning alternative to the chemical perchloroethylene. But it's on the high-tech front that carbon dioxide may make its biggest impact. "There are huge opportunities," says University of North Carolina chemist Joseph DeSimone. "I am confident that carbon dioxide will dominate several of the key steps in microelectronics."

Carbon dioxide could provide the semiconductor industry with a more environmentally sound way to scrub silicon, but it could also allow the continued miniaturization of integrated circuits. And that means faster and cheaper computers and consumer electronics. "The environmental angle will make [chip makers] look good, but they aren't going to retool only on the basis of that," says Craig Taylor, a supercritical-fluids researcher at Los Alamos National Laboratory in New Mexico. "What's interesting to industry is that supercritical carbon dioxide may be an enabling technology for going to smaller dimensions."

Scientists have known for more than a century that at 75 times atmospheric pressure and 31 °C, carbon dioxide goes into an odd state that chemists call "supercritical." In this state, the liquid and the gas forms of carbon dioxide become indistinguishable: they merge into one fluid with unusual properties. Among the strangest, the viscosity of the fluid drops to almost nothing and its surface tension goes to zero. The low viscosity means it flows unusually well with low resistance, and the zero surface tension means the fluid's surface doesn't curl up at the edges and stick to the sides of its container. The net result: supercritical carbon dioxide can flow into crevices and nooks so tiny that other liquid solvents would gum up.

Researchers at Los Alamos, the University of North Carolina and elsewhere have been exploring the possibility that using supercritical carbon dioxide—or liquid carbon dioxide hovering just below the supercritical state—could let them make features on microchips at an unprecedented level of resolution. In photolithography, the fundamental process used in chip making, a photoresist (a light-sensitive material that covers the silicon chip) is exposed to light shined through a "mask"; the exposed photoresist is then washed off, leaving a pattern on the silicon. Existing technology typically uses a water solution to wash away the photoresist. "But the structures are getting so small that the high surface tension of the water itself can be damaging," explains DeSimone. Just like honey poured over a house of cards, the water can collapse the delicate silicon features. Supercritical carbon dioxide can wash over the structures without demolishing them.

Carbon dioxide could also provide a way of laying down the ultrathin copper wires used in today's best microchips. Jim Watkins and colleagues at the University of Massachusetts recently found they could dissolve metallic compounds in carbon dioxide and pour the solution into the tight nooks and crannies of trenches etched into the silicon to form the wires. When the researchers add hydrogen gas, the compounds release their metal loads onto the silicon surfaces to create high-quality interconnects thinner than 100 nanometers.

If carbon dioxide can clean up chip manufacturing, it could provide a classic win-win situation for those balancing environmental impact and manufacturing performance in the high-tech industry. Manufacturers will be able to continue to produce chips with the shrinking features needed for tomorrow's ever faster computers. And those in Silicon Valley can save their water supplies for making decaf lattes. —*David Voss*

SUPERCRITICAL SUCCESS

New uses for carbon dioxide

APPLICATIONS	USE
Dry cleaning	Replaces perchloroethylene and organic solvents
Spin coating	Precise control of thin-film creation for photoresists and other polymers
Wafer cleaning/ drying	Water-free method for prepping silicon wafers at chip plants
Photolithography	Replaces water-based developer solution for creating resist pattern after exposure to light
Resist removal	Strip off old photoresist after etch
Polishing	Solvent for high-tech grinding and polishing in chip making

A dry-cleaning machine made by Micelle Technologies uses supercritical carbon dioxide.

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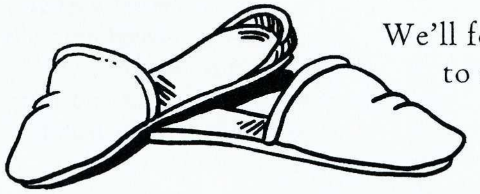

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MESSAGE IN A BOTTLENECK

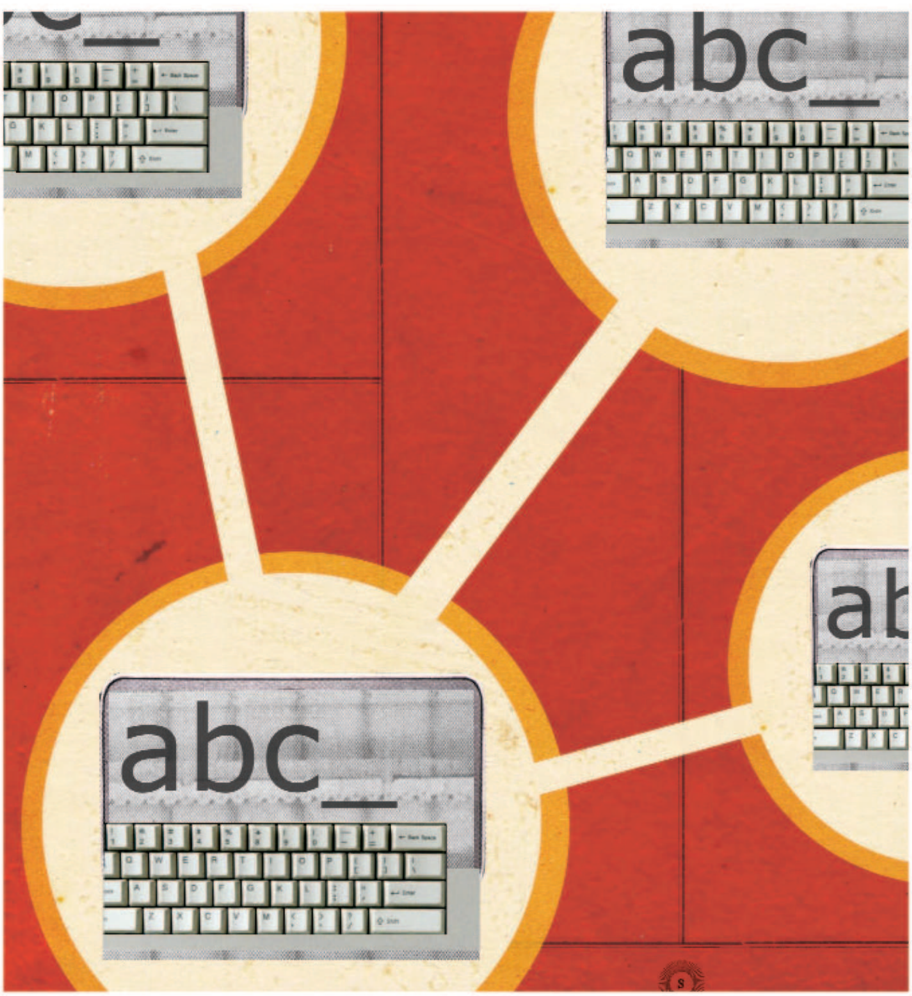
I was loading up a moving van on Martha's Vineyard the morning of September 11 when the first jet hit the World Trade Center. As soon as I heard the news I tried to call my wife, Beth, who was 150 kilometers away at our house near Boston. No dice: my desk telephone could not place a call off-island. I tried my cell phone: it didn't work either.

I desperately needed to communicate with my wife. If Boston were to be attacked, or if there were going to be more incidents in New York, then it made sense for me to stay put on the Vineyard and for her to gather up our three young children and join me. If the attacks were localized to New York City, then I wanted to return to Boston. Realizing that any attempt at a voice connection would probably be in vain, I typed a brief e-mail message on my laptop and clicked "send." A moment later Beth's pager beeped and the message appeared. She pecked out a response on its tiny keyboard, and less than a minute later I had my answer: come back to Boston.

Beth and I were not alone. In the aftermath of the terrorist attacks, many people discovered that wireless text messaging systems were consistently more reliable and more resilient than telephones. The reason, most likely, is that sending a text message requires dramatically less data than a voice conversation. This means that text systems are less prone to overloading during the kind of communications frenzy that occurred on September 11.

A plethora of wireless text messaging services are in use today—and not just for emergencies. The compact two-way pagers that link my wife and me together are an unobtrusive way to chat throughout the day. It's also possible to send two-way text messages on many cell phones—although it's much easier on some than others. The popular BlackBerry device from Waterloo, Ontario-based Research in Motion has become a powerful two-way wireless e-mail tool for many businesses: it's twice the size and twice the price of my two-way pager, but it directly integrates with many corporate e-mail systems. And then there are the wireless modems available for handheld computers like the Palm, which let you both browse the Internet and send e-mail.

Many people who have never tried wireless messaging think that it's just another techno-gadget—a technology looking for a market. But as soon as they try it, most realize that it's friendlier, faster, more reliable, less intrusive and generally a lot cheaper than making a cell-phone call. The big difference is synchronicity. With the phone, Beth and I both have to be present at the same instant. With messaging, I can send her a question when I want, and she can answer it on her own time—handy if she's changing a diaper when I try to reach her (or doing something really important, like sleeping).



JASON HOWARD STATTS

This combination of attributes has given rise in the United States to a dedicated, but perplexingly small, following for two-way wireless messaging systems. Only about 1.5 million people use the two-way text messaging systems offered by Research in Motion, SkyTel Communications of Jackson, MS, and Arch Wireless of Westborough, MA. That's just a tiny fraction of the number of people who carry cell phones—and therein lies the rub.

Two factors have severely hampered U.S. adoption of wireless text messaging. The first is diversity. Cell phones pretty much all look alike, and in the United States they all have pretty much the same user interface:

you dial a number and press a button labeled "talk" or "OK." But each of the many different two-way wireless text systems has a very different interface. This has made marketing the service much harder, because it has prevented the accumulation of a critical mass of users who provide free advertising, testimonials and demonstration.

The second problem is unification. Right now, all our two-way text systems are pretty much islands: they don't work well with other wireless services. And although every system can send and receive Internet e-mail, it is considerably easier for me to send two-way messages from my SkyTel pager to another SkyTel pager than to a device hooked up to a different service.

It doesn't have to be this muddled. Europe has avoided these problems entirely by settling on a single wireless-telephone system called GSM (Global System for Mobile communications); easy-to-use, two-way text messaging is built into the protocol. Europeans call it SMS, for Short Message Service. If you want to send a message, all you need to know is the recipient's phone number. Just dial the number, type the message onto your phone's keypad and press the send button. Voilà: instant two-way communication. The service has become extraordinarily popular. In September 2001, for instance, the system carried 23 billion text communiqués—ten times as many as the previous September.

Europeans use cell-phone-based text messaging for the same reasons that I use two-way paging with my wife: it's fast, convenient, unobtrusive and cheap. And European society has comfortably assimilated the technology. It is now well within the bounds of European business etiquette, for example, to leave your telephone on the table during a meeting and quietly scan the incoming text messages in case anything urgent comes through. "SMS resembles telepathy," says Risto Linturi, one of Finland's leading telecom consultants.

European cell-phone companies like the text messaging service too because it's a lucrative add-on. Companies are able to charge one to 10 cents for each message, even though the actual cost of sending a few lines of text is virtually nil. That's because the messages use air time far more efficiently than voice conversations do. A typical message of the maximum allowed length (160 characters) occupies the airwaves for only a fraction of a second.

Despite this overseas success, U.S. cell-phone companies have resisted boarding the Short Message Service bandwagon. The problem, it turns out, is a combination of availability and compatibility. Although virtually all U.S. cell-phone companies offer some form of two-way messaging from their handsets, they use different, incompatible formats. VoiceStream Wireless and AT&T Wireless, for instance, both offer genuine, two-way, phone-to-phone Short Messaging Service communications over their networks. But try sending a message from a VoiceStream phone to an AT&T phone and you hit a wall.

And such incompatibility isn't the worst of it. Sprint PCS doesn't allow direct two-way messaging at all. Instead, Sprint requires its customers to use their cell phones' built-in browsers to go to a special Web site that allows them to send and receive messages. This is all done with an incredibly painful system called WAP (for Wireless Application Protocol), which defies usability. Nextel Communications offers a fourth, disconnected island of two-way messaging, with interoperation only between Nextel phones.

Just about the only thing that U.S. carriers have done right is to create Internet e-mail gateways for their subscribers. Most cell phone users can now send email by tapping out a message and the recipient's e-mail address. If you send me a message from your phone and I reply, the first 100 characters or so of my reply will show up on your phone. It's better than nothing, but it's still not as good as European-style text messaging, where I'd only need to know your phone number. To e-mail your phone in the United States, I need your phone number, the name of your cell phone company, and information about how the gateway works.

Wireless text messaging is friendlier, faster, more reliable, less intrusive and generally a lot cheaper than making a cell-phone call. It's huge in Europe—but lack of a standard stymies U.S. adoption.

Some people say there's a good reason why we in the United States have not flocked to these services. The near ubiquity of e-mail means that many Americans already have a way to send two-way text messages. But e-mail is a fundamentally different medium. It's good for longer missives and for sending attached documents that you read on your desktop or laptop computer. You pick up your e-mail messages when you are at home or at work. Text services deliver messages on the go—quick notes that demand your immediate attention, like a reminder to get eggs when you are driving to the supermarket.

Here's another reason why two-way text messaging is failing in the United States: unbridled competition. Europe's telecommunications carriers got together and decided on the Global System for Mobile communications standard for wireless phones. The United States has let phone companies compete not just for customers, but in technology and standards. Alas, that competition has created a cacophony of mostly incompatible and underused systems. Maybe that's a message that our policymakers should heed.

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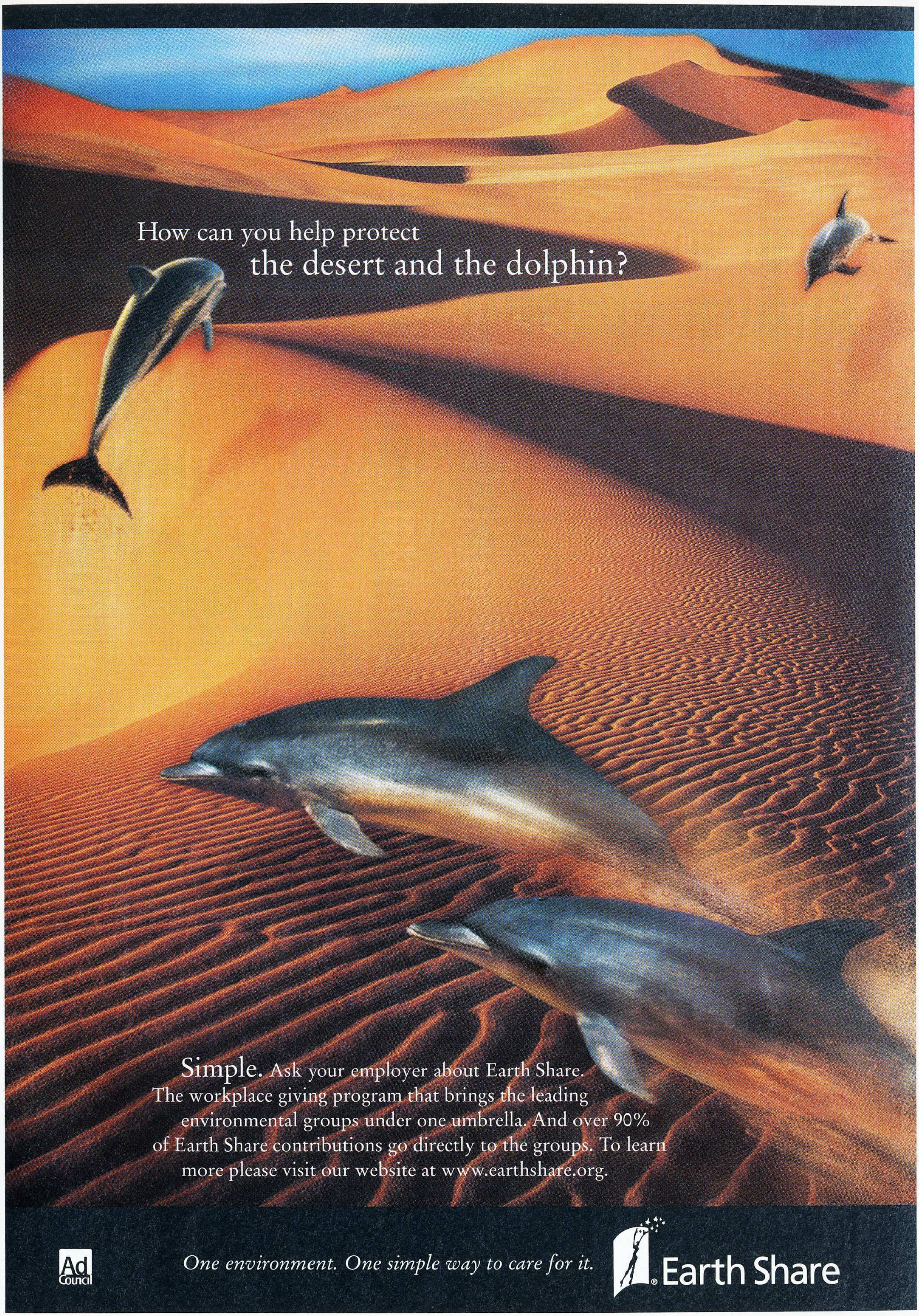
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getting over OIL

ABUNDANT PETROLEUM SUPPLIES AND RELATIVELY LOW PRICES ARE DETERRING THE TECHNOLOGICAL EXPERIMENTATION NEEDED TO DEVELOP NEW ENERGY SOURCES. COULD THE NEW TUMULT IN THE MIDDLE EAST POINT A WAY OUT?

When President George W. Bush announced last May that "we're running out of energy in America," students of history could have been forgiven for thinking ruefully of George Otis Smith. Once a formidable figure in Washington, DC, Smith led the U.S. Geological Survey from 1907 to 1930. Just after the First World War, Survey geologists assessed the state of the world's petroleum reserves—and concluded that they would be totally exhausted before 1940. Alarmed by the prospect of what he called a "gas famine," Smith charged that the position of the United States "can best be characterized as precarious."

To stave off an energy crisis, Western nations tried to secure access to the world's remaining oil, especially the then unexploited deposits in what are now Iran and Iraq. A frantic round of imperialistic dickering ensued, with the United States and France convinced that the British were stabbing them in the back. Disputes over oil spread "a film of mistrust," historian Herbert Feis lamented, over both the establishment of the League of Nations and the Allied powers' attempt to bring the fledgling Soviet Union "back into the circle of friendly nations." Only in the late 1920s did the United States, France, Britain and the Netherlands settle the issue—as far as they were concerned, anyway—by slicing up parts of the Middle East into national oil concessions, thus ensuring their supply of petroleum.

Almost immediately, the whole contretemps was shown to be pointless. Technological advances had changed the oil industry. Using devices for detecting slight variations in gravitational attraction developed by Hungarian physicist Roland, Baron von Eötvös, petroleum prospectors looked for the changes in density associated with oil fields—and discovered huge new deposits in Oklahoma and Texas. Texas crude oil was offered for as much as $1.85 a barrel in 1926; by 1931, some desperate producers were unloading it for *two cents* a barrel. The United States, barely able to handle its own glutted supply, did not actually import Middle Eastern crude for decades. Nonetheless, its willingness to meddle in the affairs of oil-producing Middle East nations helped to sully relations in that part of the world for the next 70 years.

History's mode of instruction is oracular, rarely providing simple, straightforward messages. Still, certain lessons from the "oil crisis" of the 1920s apply today. One is that even the most authoritative-seeming predictions about energy have a way of missing the mark. "I can't tell you how many people throughout history have said that in 20 years we'll have an energy catastrophe," says David Victor, director of the Program on Energy and Sustainable Development at Stanford University's Center for Environmental Science and Policy. "And they've always been wrong—always."

The "crisis" also illustrates how the technology and economics of the energy industry are inextricably bound. Baron von Eötvös developed his new gravitational techniques at the turn of the century, but oil-company geologists did not try them until fears of a shortage drove up prices. When the baron's methods were employed, they were so successful that the predicted energy famine became an energy flood.

Today, new energy technologies face similar obstacles. In the midst of President Bush's claims that the nation is facing a crisis of supply, environmentalists are predicting another kind of energy crisis: global warming. But except for electricity prices in parts of the U.S. West, energy prices have recently been low in historic terms. In consequence, most nations—and most energy companies—have few financial incentives to pursue new technologies, even if they would produce more abundant or cleaner energy. "We're living in a super price-sensitive and competitive market," Victor says. "Companies are totally preoccupied with short-term survival. With that kind of mentality, you shouldn't be surprised that energy research budgets have been on the skids for years." Indeed, some economists suggest that the best hopes of alternative-energy proponents may come from an unexpected, even abhorrent quarter—that the global tumult created by the terrorist attacks that began last September will in one way or another create uncertainty about energy supplies, perhaps opening up opportunities for new technologies.

AWASH IN OIL

Will there be an energy crisis of the sort invoked by President Bush? One perhaps precipitated by antipathies in the Middle East? Until September 11, it was widely believed that the likelihood of a calamitous shortfall in supply was much lower than it had been in the past.

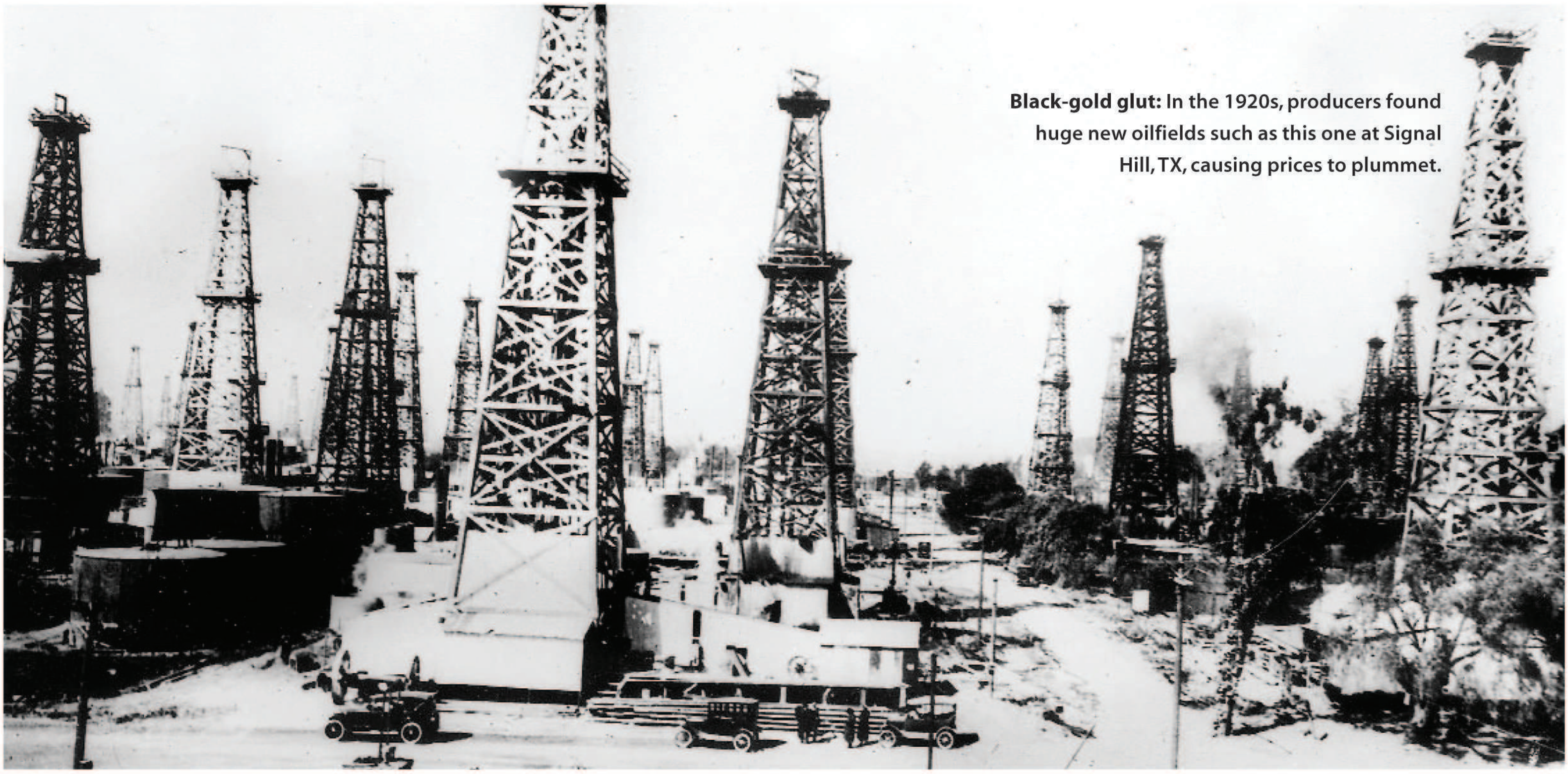
Consider the early 1970s, a time of heightened awareness of geopolitical and environmental vulnerabilities. The Club of Rome, an international group of 100 scientists, businesspeople and political figures, asked four political scientists in 1971 to use computer models from MIT to predict the future of the world. *The Limits to Growth*, in which the results were published a year later, became an international cause célèbre that sold nine million copies in 29 languages. Among the study's major conclusions: the world was going to run out of petroleum by 1992, creating an energy catastrophe.

It didn't happen, not least because by 1992 the world had already experienced an entirely different kind of energy disruption. Just as the book appeared, several Middle Eastern nations nationalized Western oil companies' assets. Because the value of the dollar was falling, petroleum prices, then as now denoted in U.S. dollars, also fell. The new owners of the Western oil assets became unhappy. United States support of Israel during the 1973 Arab-Israeli war made them unhappier still. The Organization of the Petroleum Exporting Countries (OPEC), dominated by Muslim nations, embargoed sales to the United States. Oil and gasoline prices shot up.

All of this was terrible for Western nations' economies. Between the early 1970s and early 1980s, the price of oil went up by a factor of 10. In consequence, U.S. expenditures on energy, as a fraction of gross domestic product, almost doubled, from eight to 14 percent. (These figures, like others in this article, come from the Energy Information Administration of the U.S. Department of Energy.) Rising energy costs helped push unemployment and inflation to record highs; the U.S. economy lurched like an unseaworthy boat from recession to recession. "It was a really awful time," says Hal Varian, an economist who is dean of the School of Information Management and Systems at the University of California, Berkeley. "When you're doing economic comparisons you sometimes have to throw out the statistics from those years—the numbers were so freakishly bad, such outliers, that they're not very useful for normal economic analysis."

Buffeted by the oil shocks, Americans profoundly—and, it seems, permanently—changed their relationship with energy. Between 1973 and 2000, U.S. energy consumption jumped by about a quarter. But this rise came mostly from the concurrent rise in U.S. population. In fact, U.S. per-capita energy consumption—that is, consumption per American—actually declined slightly from 1973 to 2000. Amazingly, the drop occurred despite the seemingly unslakable U.S. appetite for power-hogging air conditioners, electricity-drinking computers and, more recently, gas-guzzling sport-utility vehicles.

Paradoxically, the United States imports a greater proportion of its petroleum than ever before—but needs it less. In the 1970s, notes Howard Gruenspecht, an economist at Resources for the Future, a Washington, DC-based research group, "the United States used oil for all kinds of things—home heat, electrical power, you name it. Now the great bulk of it is used for just one purpose: transportation." Oil imports have quadrupled since the OPEC embargo, because U.S. drivers continue to be addicted to petroleum. But oil use has fallen in many other sectors of the economy. At the time of the embargo, for example, almost one-fifth of U.S. electricity was generated by petroleum; today the figure is less than one one-hundredth. In 1973, one out of every four houses in the United States was heated by crude oil; this year it is fewer than one out of ten. With the nation no longer completely dependent on one energy source, the U.S. economy has significantly more resilience against energy



Black-gold glut: In the 1920s, producers found huge new oilfields such as this one at Signal Hill, TX, causing prices to plummet.

HULTON/ARCHIVE

shocks than before. "Retail gas prices came close to doubling between the spring of '99 and the spring of 2000," says Pietro Nivola, a senior fellow in governmental studies at the Brookings Institution, a Washington, DC-based think tank. "Consumers screamed about it, but overall, the impact was small, because the whole economy is less dependent on petroleum."

To the extent that it was intended to increase the geopolitical power of OPEC nations, in fact, the embargo of the 1970s backfired. "The rise in prices made new investments in oil very attractive," says Fadhil Chalabi, director of the Centre for Global Energy Studies in London, who was the acting secretary general of OPEC for much of the 1980s. "Oil companies found huge new supplies of oil in places like west Africa, the Caspian Sea, the North Sea and Mexico." The flood of new oil put the traditional OPEC nations—especially Saudi Arabia, by far the cartel's dominant producer—in an awkward position. To keep prices high, Saudi Arabia and neighboring Persian Gulf states had to cut production. But when they cut production, they lost the income from selling oil. They were losing money so that others could profit. In the mid-1980s these nations lifted the limits; oil prices sank.

But it may have been too late, if Chalabi's perspective is correct. Like the United States, the West as a whole had become less reliant on petroleum in general and Middle Eastern petroleum in particular. "Even in Europe, the dependence on gulf oil has fallen dramatically over the last 20 years," Chalabi says. "Europe has gone from importing 70 percent of its oil from the Persian Gulf to less than 30 percent because of the increases in North Sea oil and oil from west Africa." Worse from the OPEC perspective, any attempt to raise prices will accelerate the transition away from oil to natural gas, coal and nuclear power.

Noting these factors, both the U.S. Energy Information Administration and the International Energy Agency (a Paris-based group with representatives from 26 nations) project that oil will flow in the future like never before. Desperate for hard currency, new Caspian Sea oil centers like Russia, Azerbaijan, Kazakhstan and Turkmenistan have opened the spigots wide; unable to stop them without shutting themselves out of the market, Persian Gulf oil states watched prices fall to a two-year low in November. Iraq, which has been more or less at war with the United States for a decade, nonetheless sells it 613,000 barrels of oil a day. It would like to sell more—Saddam Hussein needs the cash. "It used to be believed that overwhelming demand will make us run out of oil," Chalabi says. "In fact, the real question is whether there will be enough demand for oil to use the supply."

PLAYING CHICKEN

Continued low energy costs as far as the mind can envision—what could be wrong with that? Anti-global-warming activists know the answer: it's hard to launch novel energy technologies when the old methods are cheap, even if the new techniques would provide important benefits. Indeed, if history is any guide, the biggest obstacle to a technical solution to climate change may not be devising mechanisms to reduce carbon emissions, but making them cheap enough to compete in the market.

According to United Nations estimates, the United States, which has one-twentieth of the world's population, is responsible for more than a quarter of the carbon dioxide pumped into the atmosphere every year—about 5.6 billion metric tons in 1999, the latest year for which estimates are available. About a quarter of that total, 1.5 billion metric tons, came from energy. (The rest is due to a variety of sources ranging from cement production to agriculture to termites.) The great majority of atmospheric scientists believe that these carbon emissions will lead, sooner or later, to climatic change. If and when the greenhouse effect substantially heats the planet, U.S. energy consumption will bear a disproportionate share of the blame.

The problem is that curbing these emissions would have a disastrous impact on economic growth. When activists decry global warming, they often single out the American love affair with driving for special opprobrium. But the automobile is far from the only culprit. In 1999, the use of energy by industry released almost exactly as much carbon dioxide as did the national fleet of cars, trucks, planes and sport-utility vehicles;

households emitted almost two-thirds as much. Coal-fired electricity plants, gas grills and ranges in the home, agricultural and timber wastes—the list of greenhouse producers is as varied as postindustrial society itself. (Nuclear power plants are an obvious exception, but activists view them, rightly or wrongly, as posing other unacceptable risks *[see "The Next Nuclear Plant," p. 54]*; hydroelectric dams create their own ecological problems.)

Finding ways to curb emissions in all of these areas is a "sobering prospect," says Paul Joskow, an energy economist at MIT. "With the best will in the world, it's difficult to see as a practical matter how it could be done." And with oil prices falling to $17 a barrel last fall—and billions of dollars already invested in the nation's petroleum-based infrastructure—there are few economic motivations for adopting new technologies. Take fuel cells, for example. Energy researchers like fuel cells because they are silent, efficient, have no moving parts and produce no direct carbon emissions. Unfortunately, fuel cells also have drawbacks. They typically have to warm up, sometimes for as long as half an hour. Worse, the hydrogen in fuel cells is usually stored under high pressure, creating the risk of a *Hindenburg*-like fireball *(see "Fill 'er Up with Hydrogen,"* TR *November/December 2000)*.

But even if these and other technical challenges can be overcome, proponents of fuel cells will still have to convince ordinary Americans to replace their internal-combustion cars. When horseless carriages appeared on the scene, people could get around more conveniently: it was much easier to drive into a city and park a car than to ride there and find lodging and food for a horse. By contrast, fuel cell cars provide exactly the same service as gasoline cars except for producing less of an invisible, odorless gas. Moreover, they will cost more than regular cars, at least in the beginning. Yet even if consumers take the plunge, they won't actually be able to drive anywhere unless businesses simultaneously spend billions of dollars establishing a network of hydrogen dealers with as wide a service area as today's profusion of gas stations.

Petroleum politics: Disputes over access to oil wells like this Persian pump, photographed in 1925, have sullied Middle Eastern diplomacy for decades.

CORBIS

As fuel cells show, new energy technologies always face what Jostrow calls "a classic chicken-and-egg problem." To attract consumers, fuel cell vehicles must cost the same as or less than conventional automobiles. But that can't happen until enough hydrogen vehicles have been sold that manufacturers can lower prices. The same is true of hydrogen filling stations—they won't be present in sufficient abundance until a lot of fuel cell cars are on the road, but fuel cell cars can't be on the road in numbers until companies put up hydrogen filling stations.

Similar problems affect most new technologies, says Stanford's Victor. "To replace coal-generated electricity with wind farms—even if that was technically feasible—you'd still have to build the wind farms," he says. "You have to learn how to design them, how to operate them, how much redundancy you need in the system. That's all additional costs. Meanwhile, you already have the coal plants."

COST OF CHANGE

To environmentalists, the economic obstacles faced by new energy technologies are maddeningly unfair. The reason is that the costs of global warming—unlike costs such as labor, insurance and raw materials—are not included in the price of energy. In other words, the price of the kilowatt-hours that heat U.S. homes includes the power company's cost of fighting lawsuits brought by environmental groups, but not the potentially enormous costs to society from climatic change. Economists, for their part, readily agree that this is a problem. Unfortunately, it is not clear what to do about it.

In economic terms, these unaccounted-for items are known as externalities—costs or benefits that are not adequately reflected in market prices. The problem of incorporating externalities into prices has long bedeviled economics. (Textbooks on externalities were published as long ago as 1917.) A classic example of the awkwardness of handling externalities is the case of the small business that releases a blast of noxious gas and damages its neighbors' property—wrecking the paint on cars and houses, say. All 50 states have enacted private- and public-nuisance laws that permit individuals and the government to take the offenders to court and force them to pay for the cleanup. If that doesn't stop further emissions, injunctions can follow. Eventually, in theory, miscreants realize that they can't avoid legal action and choose to stop polluting, presumably passing the costs of using cleaner technology on to consumers. In this fashion, pollution abatement becomes incorporated into the market price. But as almost everyone agrees, the methods for doing it—lawyers, litigation and legislation—are halting and slow.

Global warming, alas, fits poorly even within this awkward framework. To begin with, much of the problem is due to entire societies, not specific corporations. And because nobody knows the rate at which global warming will occur, or precisely what the effects will be when it takes place, there's no simple target to shoot for. Global-warming activists often suggest a "carbon tax" on fossil fuels to account for the future costs of climate change. Fair

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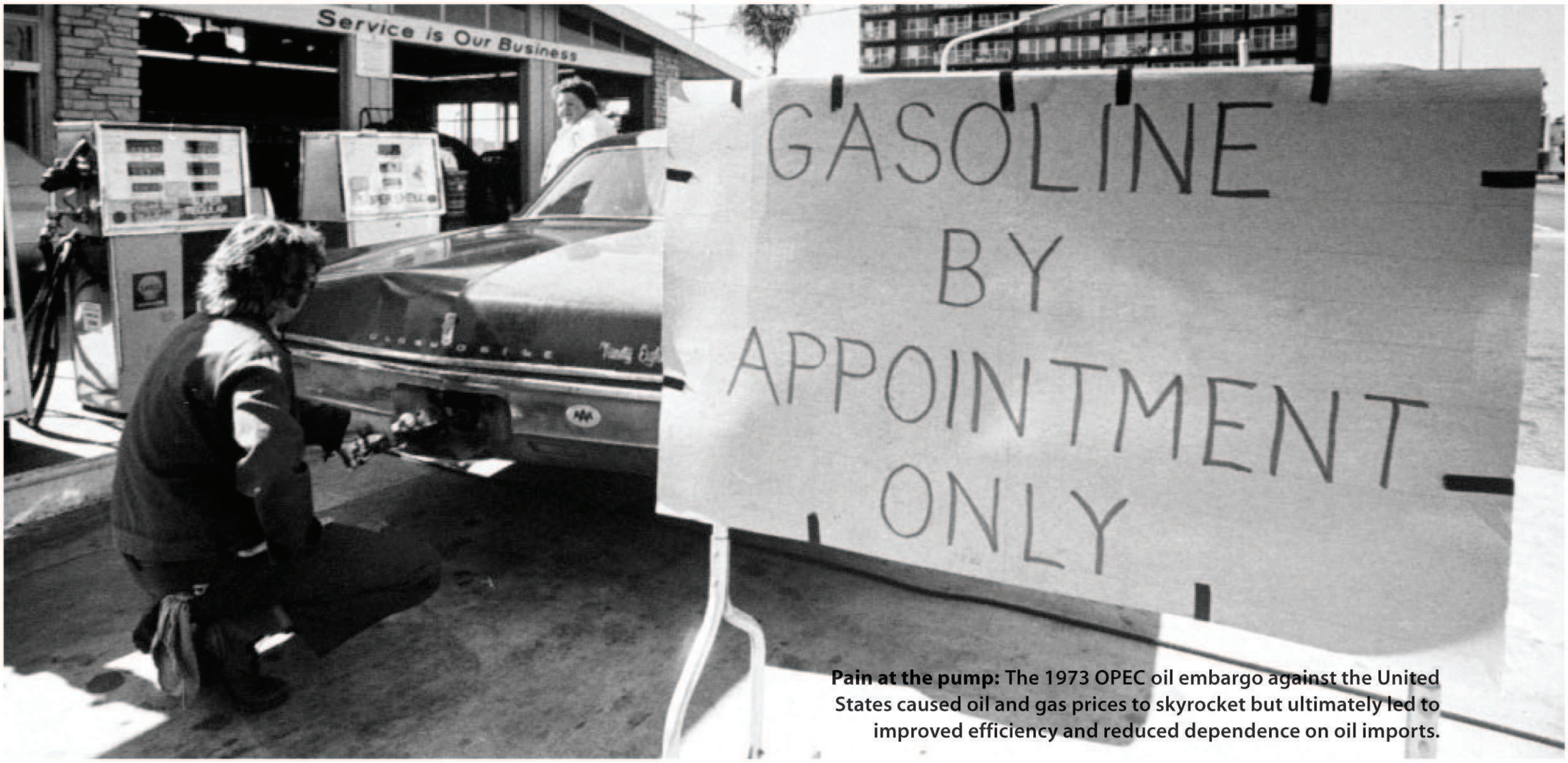

Pain at the pump: The 1973 OPEC oil embargo against the United States caused oil and gas prices to skyrocket but ultimately led to improved efficiency and reduced dependence on oil imports.

TIMEPIX

enough, but how high will those costs be? If U.S. consumers pay $1 billion a year, would that be enough to cover the problem? How about $10 billion? $100 billion? The level of economic damage that might be inflicted by greenhouse gas abatement is so uncertain that even the Kyoto treaty on global warming, to date the most ambitious attempt to address climate change, says not a word about what the "right" level of emissions should be.

Compounding matters, the political system has shown little inclination to wrestle with the problem of greenhouse gases. Bill Clinton, arguably the most green-friendly president in decades, refused even to submit the Kyoto treaty to the U.S. Senate. Notoriously, one of President George W. Bush's first acts of office was to abandon the Kyoto treaty—without feeling it necessary to present any alternative proposal.

Even energy research has hit hard times. According to James J. Dooley, an energy researcher at the Pacific Northwest National Laboratory, U.S. public and private investment in energy R&D have been declining steadily for 20 years. Between 1979 and 1999 public energy-research spending fell by more than two-thirds in real terms. And every other developed nation except Japan has also cut research funding. "With few exceptions, energy R&D simply isn't on the radar," he says.

"Look at the projections," says Dermot Gately, an economics professor at New York University. "Cheap petroleum forever. Cheap natural gas. Cheap coal forever—the United States is the Saudi Arabia of coal. It's energy Nirvana. Almost every solution to climate change involves driving up those wonderfully low prices. Where's the mandate for change in that?"

Without clear economic benefits, technological change is most likely in niche markets. An example is the current tests of natural-gas engines in taxi fleets in Long Beach, CA, Atlanta, New York City and other cities. New Zealand, too, has switched most of its taxi fleet to natural gas. (Natural gas burns more cleanly because it is chiefly composed of methane, a simple molecule whose combustion produces carbon dioxide and water vapor but almost no soot or sulfur dioxide *[see "Hitting the Natural-Gas Jackpot," p. 68]*.) Why taxis? Urban air pollution is disproportionately due to taxis, which run constantly, under the most taxing traffic conditions. In addition, taxis, which are confined to particular cities, don't need a nationwide network of alternative-fuel stations.

"The idea in all of these things is to come in from the margins to the center," says Stanford's Victor. "But it's never easy." Once the technology has penetrated the niche, engineers can work on bringing the costs down. For those who want clean energy fast, though, the best hope in Victor's view "is for what people now like to call a 'disruptive' technology—something that forces huge change. But those don't happen often."

Curiously, Gately suggests, innovators may take some heart from the historical record. "We've never been good at predicting energy supplies," he points out. "Something always happens." Although he, like most energy economists, thinks it unlikely that an event like a terrorist attack could have a long-term, significant impact on energy supplies, he says it's "prima facie foolish" to discount the possibility of catastrophes in the Middle East or the Caspian Sea. The energy industry can be incredibly volatile—recall that in the five years between 1926 and 1931, the price of Texas crude fell more than 98 percent. In our own day, utilities that spent the summer of 2001 wrestling with electricity price spikes in California spent last fall trying to gauge the impact of war in Afghanistan on the nearby, oil-rich nations around the Caspian Sea. If the U.S. campaign against terrorism creates an explosive reaction, the regime of low oil prices may collapse. Imagine, for example, the effects of terrorist attacks against key pipelines or oilfields. "In one way or another," Gately says, "we've been fighting [in oil country] since Desert Storm. You have to ask, would Americans be more willing to think seriously about energy if, God forbid, something unexpected happened over there? Would they maybe start thinking about fuel cells and carbon taxes? It's always possible."

So the silver lining of tumult in the Arab world might be a greater willingness to address global warming? "I wouldn't put it that way," Gately says. "I'd say that the crystal ball is as murky as ever. And since we don't know the future, you can't rule out the possibility of a happy outcome." TR

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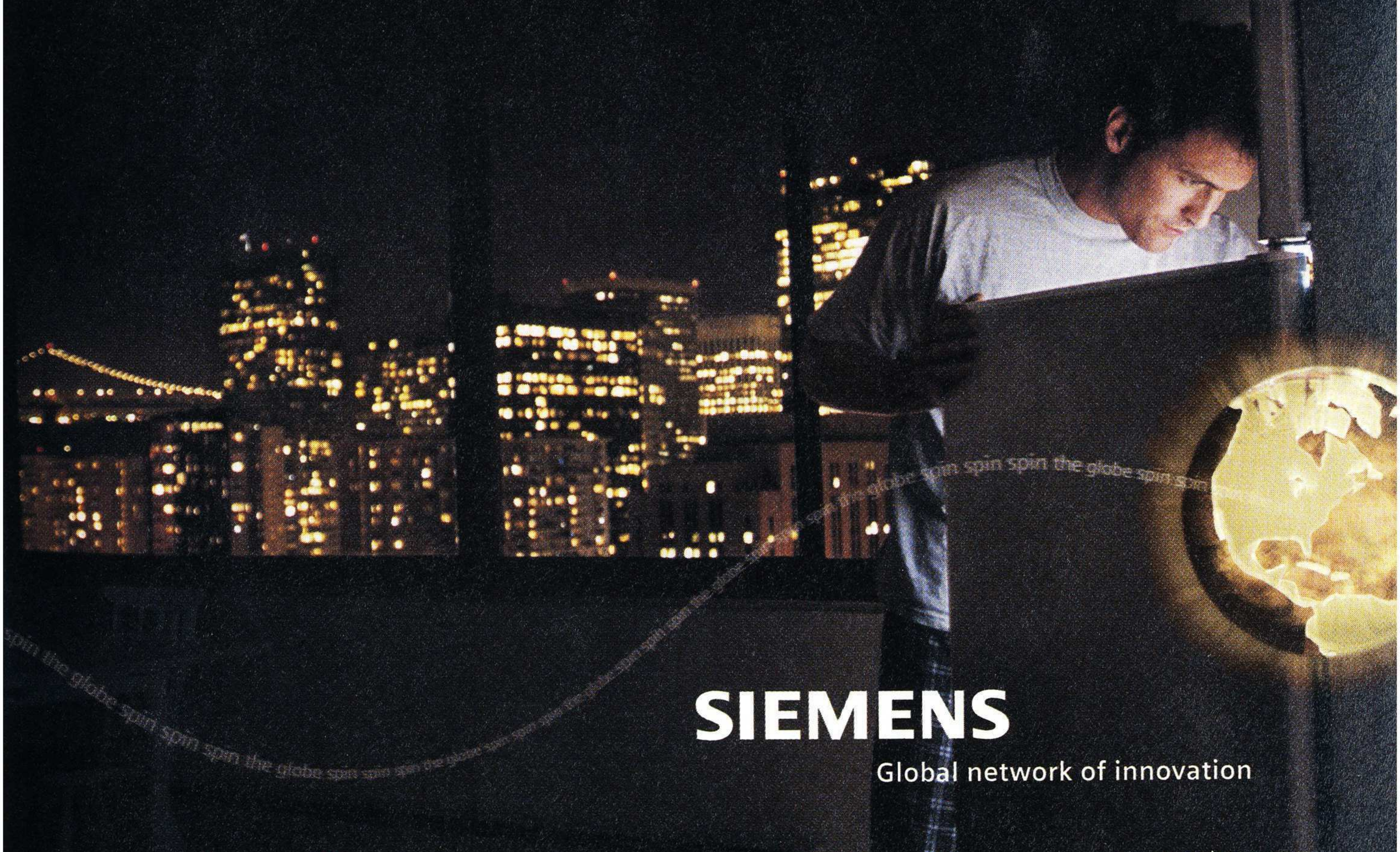

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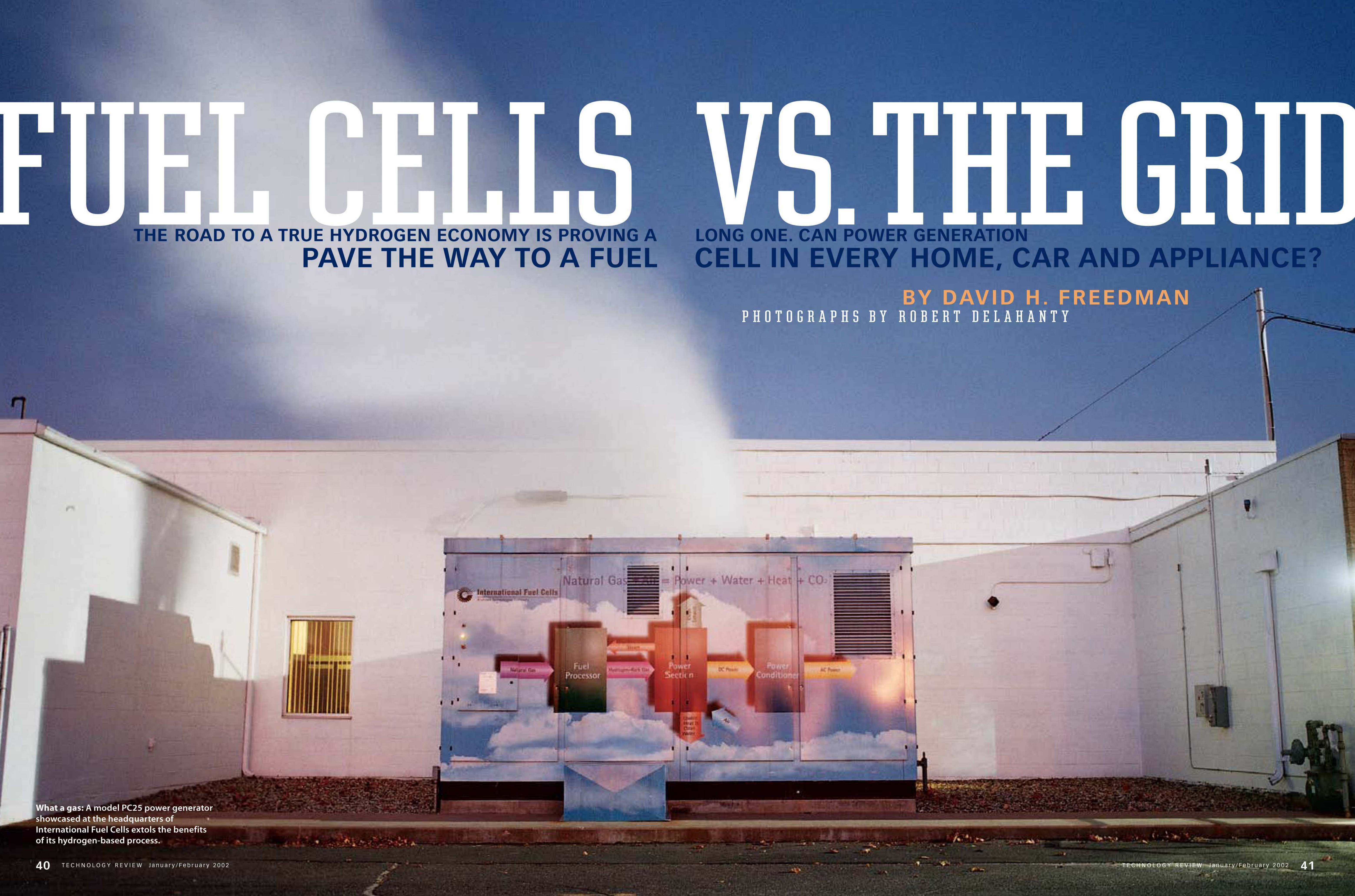
FUEL CELLS VS. THE GRID

THE ROAD TO A TRUE HYDROGEN ECONOMY IS PROVING A LONG ONE. CAN POWER GENERATION PAVE THE WAY TO A FUEL CELL IN EVERY HOME, CAR AND APPLIANCE?

BY DAVID H. FREEDMAN

PHOTOGRAPHS BY ROBERT DELAHANTY



What a gas: A model PC25 power generator showcased at the headquarters of International Fuel Cells extols the benefits of its hydrogen-based process.

FOR AN ELECTRIC-POWER GENERATING STATION, MOHEGAN-2 CUTS A SINGULARLY UNIMPRESSIVE FIGURE. THERE ARE NO COOLING TOWERS RAKING THE SKY, NO FOREST OF TRANSMISSION TOWERS, NO VAST TURBINES, NO GIANT PADDLES REVOLVING IN MIGHTY RIVERS. BASICALLY, IT LOOKS LIKE A VERY TALL DUMPSTER.

But when it is installed as a backup generator at the Connecticut casino Mohegan Sun, after which it is named, the gently humming Mohegan-2 will turn in a performance that any conventional generating plant would be hard pressed to match: it will derive energy from fuel without burning it, turning out 200 kilowatts of electricity, usable heat, and water of a purity that no mountain spring could match while only producing a modest amount of carbon dioxide. Most impressive of all, over time it very well may be able to do all this almost as cheaply as—and more reliably than—conventional power plants.

Mohegan-2, along with a host of similar hydrogen-fueled power stations now jumping from long research and development efforts into the commercial arena, could be ushering in the age of the fuel cell. Fuel cells, which electrochemically wring energy out of hydrogen, are as quiet, clean and mechanically simple as a battery but as easy to refuel as an internal-combustion engine. Long ballyhooed by many as the inevitable successor to gas-guzzling, pollution-spewing car engines, fuel cells have always been hampered by high manufacturing costs. But a growing number of companies are confident they are now on the verge of bringing prices for fuel cells down to levels where they can compete—if not with car engines, then with conventional electric-power generating equipment. If the market for such units takes off, that success could very well trickle down to the manufacture of other mass-market fuel cells for homes and even individual appliances. The resulting "hydrogen economy," where nature's most abundant substance replaces fossil fuels as the electricity elixir of choice, would eventually be one of vastly increased efficiencies and dramatically cleaner air.

Not that an upcoming hydrogen dynasty is by any means a sure thing. Besides a host of technical kinks that remain to be ironed out, there are also infrastructure challenges, such as how to make pure hydrogen available to consumers and where to get fuel cells serviced. There are even fundamental questions about the market potential of fuel cells—namely, will the public be willing to dump familiar technologies in favor of fuel cells that are likely to carry a price premium? Many experts believe it will. "After years of really intense research, we don't see any roadblocks that we don't know how to get around to converting our energy systems to fuel cells on a large scale," says Kenneth Stroh, who heads fuel cell research efforts at Los Alamos National Laboratory in New Mexico. "We still have improvements to make, but if we can get them this will be a game-changing event."

THE "HYDROGEN ECONOMY," WHERE NATURE'S MOST ABUNDANT SUBSTANCE REPLACES FOSSIL FUELS AS THE ELECTRICITY ELIXIR OF CHOICE, WOULD EVENTUALLY BE ONE OF VASTLY INCREASED EFFICIENCIES AND DRAMATICALLY CLEANER AIR.

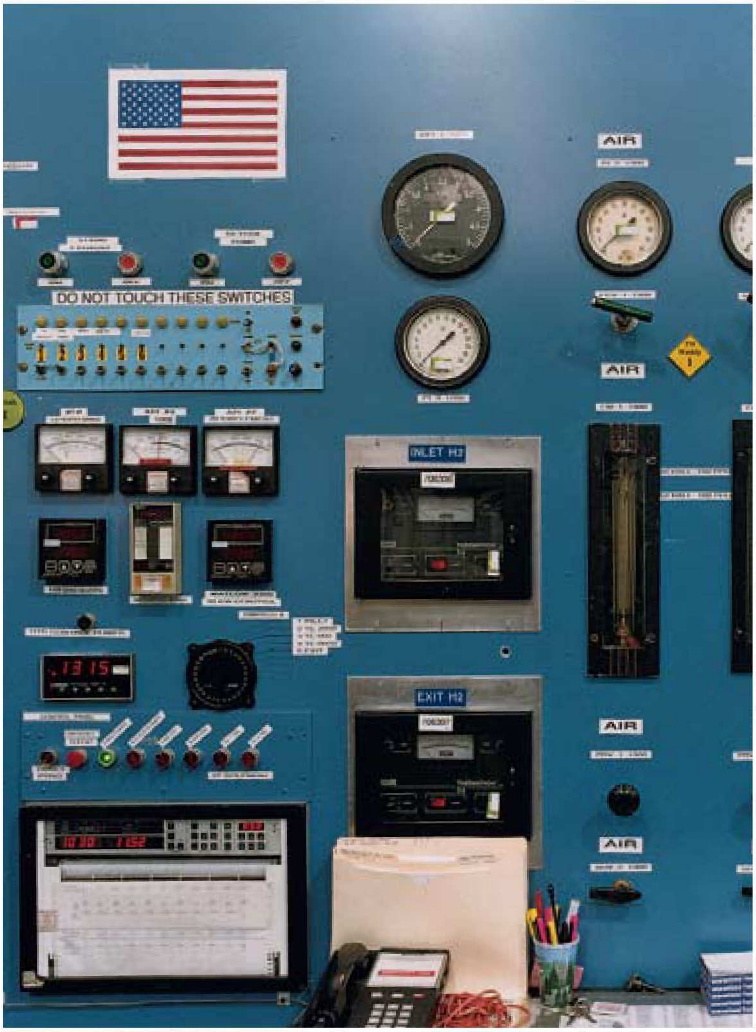
POWER TO THE PROTONS

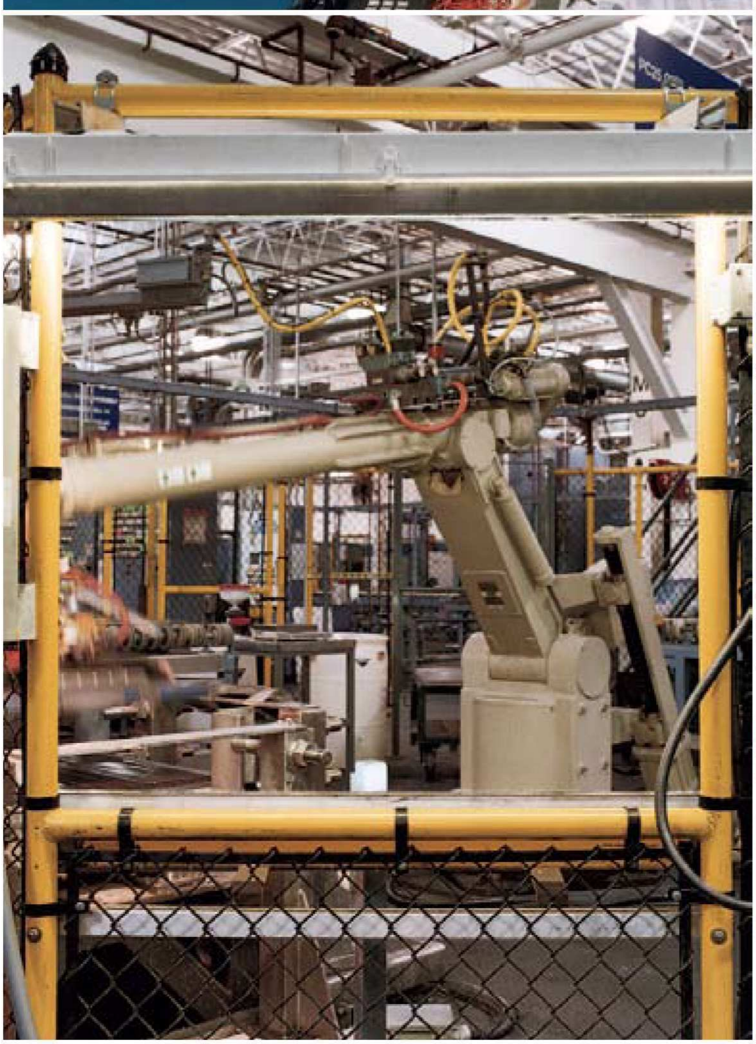
The dream of a hydrogen economy is a long-standing one. Fuel cells have been around since 1839, when British physicist William Robert Grove built a device that could reverse electrolysis, which most of us remember from junior high chemistry as the process of splitting water molecules into their constituent hydrogen and oxygen atoms simply by sending a mild electric current through water.

In a fuel cell, hydrogen and oxygen are combined to produce water and electricity. The core component of most fuel cells today is a catalyst-coated electrolyte sandwiched between two conducting plates. Hydrogen enters one of the plates, and oxygen from the air enters the other; the hydrogen then pushes through the electrolyte to get at the oxygen. Along the way, the catalyst induces the hydrogen atoms to give up their lone electrons, which are blocked by the electrolyte, leaving a pool of abandoned electrons in the first plate while the hydrogen ions migrate through to the other plate. Hooking up a wire between the two plates results in an electric current, as the electrons stream through the wire to link back up with the hydrogen ions, at which point the reconstituted hydrogen atoms combine with oxygen atoms to create water. The current will continue as long as fresh hydrogen is ushered into the first plate. To achieve high power outputs, sets of plates can be stacked together.

Cheap oil and the economies of the mass-produced internal-combustion engine conspired for well over a century to keep fuel cells out of sight and mind. But in the 1970s, concerns about air pollution and the reliability of the oil supply inspired renewed interest in the technology. Because fuel cell processes scale up and down without loss in efficiency, product development today ranges all over the map. Motorola, for example, wants to put fuel cells on chips that could power cell phones that take fountain-pen-cartridge-like hydrogen refills *(see "A Fuel Cell in Your Phone,"* TR *November 2001)*. Others seek to use them to run electric-power generating stations big enough to meet the needs of a small city. The federal government has been spending about $90 million a year on fuel cell research (though funding for all alternative-energy projects is expected to shrink under President Bush).

But the real attention in fuel cell research has been focused on cars. Faced with the ever present pressure to lower polluting emissions and the natural limitations of the internal-combustion engine, auto manufacturers have collectively poured over $2 billion into fuel cell research and development—both internally and in support of joint ventures such as DaimlerChrysler's collaboration with fuel cell manufacturer Ballard Power Systems, of Burnaby, British Columbia *(see "Fill 'er Up with Hydrogen,"* TR *November/December 2000)*. But today's very best fuel cells, though cleaner burning, still don't come within honking distance of Detroit's worst-performing engines when it comes to getting good power out of a light-




Steps to a cell: Fuel-processing monitor (top left); electrode assembly (top right); fuel cell stacker (bottom left); vacuum chamber test (bottom right).

It's a wrap: The PC25 fuel cell stack is readied for the test stand, where it will undergo performance tests before being integrated into the dumpster-sized housing.

weight, cheap, supportable package. And besides, the internal-combustion engine may be the most entrenched technology in existence—tooled and retooled over a century and a half to reach the limits of performance and reliability, manufactured in enormous quantities, and supported by a ubiquitous refueling and repair infrastructure. Since no one's going to produce lots of fuel cells without first establishing a large market, and since the automobile industry lacks the immediate incentive to perfect the technology, the quest for automotive fuel cells is faced with a catch-22. "People get all excited about the hydrogen economy," says Joel Swisher, a consultant with the Rocky Mountain Institute in Snowmass, CO. "But when it comes to figuring out how to get from here to there, the thinking grinds to a halt."

Over the past two years, fuel cell manufacturers have become convinced they've seen a route around this dilemma. Their basic thinking now is that the best way to crack the automotive market is to first build the needed fuel cell production infrastructure and economies of scale by selling the devices in a smaller but less challenger-resistant market. That market, says a growing consensus of experts and businesses, is electrical-power generation: although fuel cells cost about 10 times as much to manufacture as a typical car engine, they are now only about twice as expensive as comparable fossil-fuel power generators. "The R&D and large-scale investment has been on the automobile side," says Los Alamos's Stroh. "But it's probably true that the first products will be on the power generation side."

Many players in the fuel cell manufacturing business have at least partly shifted their attention from the automobile arena to the power generation market. Among them: Ballard, now working to bring out units for residential and portable applications; H Power in Clifton, NJ, which is preparing a 4.5-kilowatt unit; and Plug Power in Latham, NY, a General Electric-backed company which will begin shipping the GE HomeGen 7000 this year. Even General Motors has announced plans to bring out a fuel-cell power-generation product.

One company that inarguably has a head start in this suddenly glamorous subindustry is International Fuel Cells of South Windsor, CT. Not only has the company long been developing fuel cells aimed at power generation applications, it has actually been selling them for nearly 40 years. Back in the 1960s, the company delivered the three fuel cells used in Apollo spacecraft to generate electricity, and later did the same for the space shuttles. While those fuel cells have never had any commercial application—they rely on costly gold-plated components, for one thing—International Fuel Cells leveraged its experience with them to design a unit called the PC25, a device that generates 200 kilowatts of power, enough to meet the needs of a medium-sized office building. Over the past six years the company has sold more than 220 PC25s in 17 countries to a variety of businesses, schools and government agencies that wanted to replace, supplement or back up electricity from local utilities.

The core component of the PC25 has the sandwichlike design found in most fuel cells. The outside of the sandwich is composed of two conducting plates riddled with channels for ushering gases in and out. In between the plates is an electrolyte efficient at conducting protons; the electrolyte is surrounded by a platinum-based catalyst.

The electricity production process in the PC25 begins when natural gas is piped through a standard gas utility connection into the unit's fuel reformer, which is essentially a mini chemical plant that enlists a small series of heat-based processes to convert natural gas, methane or even gasoline into hydrogen, with carbon dioxide left over. After conversion, hydrogen gas is pulled through the channels of one of the plates and into contact with the catalyst-coated electrolyte, where the catalyst strips the electrons from the hydrogen atoms.

After the electrons reach the second plate and link back up with the protons, the reconstituted hydrogen atoms combine with oxygen atoms in the air to create water, helped along by the catalyst. Some of the water is absorbed by the electrolyte, which won't work if it dries out; the rest of the water is channeled to a tank, where it can be drained off. Each sandwich, or cell, in the PC25 puts out less than a kilowatt of power; to achieve its full 200-kilowatt output, a PC25 uses a stack of 272 of these cells.

When employed as a utility-power backup, the PC25 typically remains in constant operation, churning out electrical power that's directed into the utility's power grid (for which the PC25's owner normally receives credit); if the utility power fades or cuts out, an electrical switch redirects the PC25's output from the grid to the local facility in a fraction of a second, keeping the facility flush with power.

Why would anyone want to switch from conventional electric-power sources to a fuel cell like the PC25? One might assume the greatest virtue of a fuel cell is that it eliminates the need for fossil fuel, currently the source of about two-thirds of U.S. electrical energy. Considering that hydrogen accounts for about two-thirds of all the atoms that constitute our planet, being able to harness it as a source of energy almost sounds too good to be true.

It is. The hitch is simple: hydrogen may be all around us, but it's chemically locked up in water and other molecules. As it turns out, the only practical source of hydrogen available now is the same one that we've long relied on: hydrogen-rich hydrocarbons, which, practically speaking, means fossil fuels. To extract hydrogen, the fuel reformers themselves need to be powered.

Obviously, having to run fuel cells on fossil fuels—and heat and cool them—undercuts some of their advantage over conventional power plants such as those using natural-gas-burning turbines or coal-fired furnaces. But it doesn't eliminate that advantage. Even when encumbered with natural-gas-fed reformers, fuel cells produce no emissions other than carbon

TODAY'S VERY BEST FUEL CELLS, THOUGH CLEANER BURNING, STILL DON'T COME WITHIN HONKING DISTANCE OF DETROIT'S WORST-PERFORMING ENGINES WHEN IT COMES TO GETTING GOOD POWER OUT OF A LIGHTWEIGHT, CHEAP, SUPPORTABLE PACKAGE.

dioxide. To be sure, carbon dioxide is a greenhouse gas; but because fuel cells are more efficient than fuel-burning plants, they produce far less of it.

That efficiency is the key to selling fuel cell power generators. The PC25 operates at an efficiency of about 40 percent, meaning that nearly half the energy it takes in is converted to electricity, with the rest lost as heat. In comparison, the 250-kilowatt gas turbines that organizations normally purchase as alternatives or supplements to utility power operate at about 30 percent efficiency *(see "Power to the People," TR May 2001)*. The PC25's efficiency edge translates to a savings of about 30 percent in fuel costs. The edge is widened for customers who can make use of a fuel cell's waste heat, much of which is easily captured from the clean air and water removed from the cell; the heat from turbines, in comparison, is usually tied up with noxious emissions.

Unfortunately, for most power users this edge is wiped out by fuel cells' higher purchase price. A typical PC25 setup comprising an 800-kilowatt bank of four units goes for nearly $4 million, compared to less than $2 million for a comparable gas turbine generator. But James Bolch, International Fuel Cells' manufacturing head, believes he can get the production costs for the company's next generation of fuel cells to competitive levels. For starters, the company is abandoning its current cell design, with its phosphoric-acid electrolyte, and moving to a cell whose electrolyte is a thin plastic membrane—which is becoming an industry standard because it is less expensive to produce. In addition, the company is exploring new techniques for applying the $20-per-gram platinum-based catalyst in thinner coats without sacrificing performance, as well as plate designs that add efficiency by more effectively ushering hydrogen to the membrane and channeling residue water away.

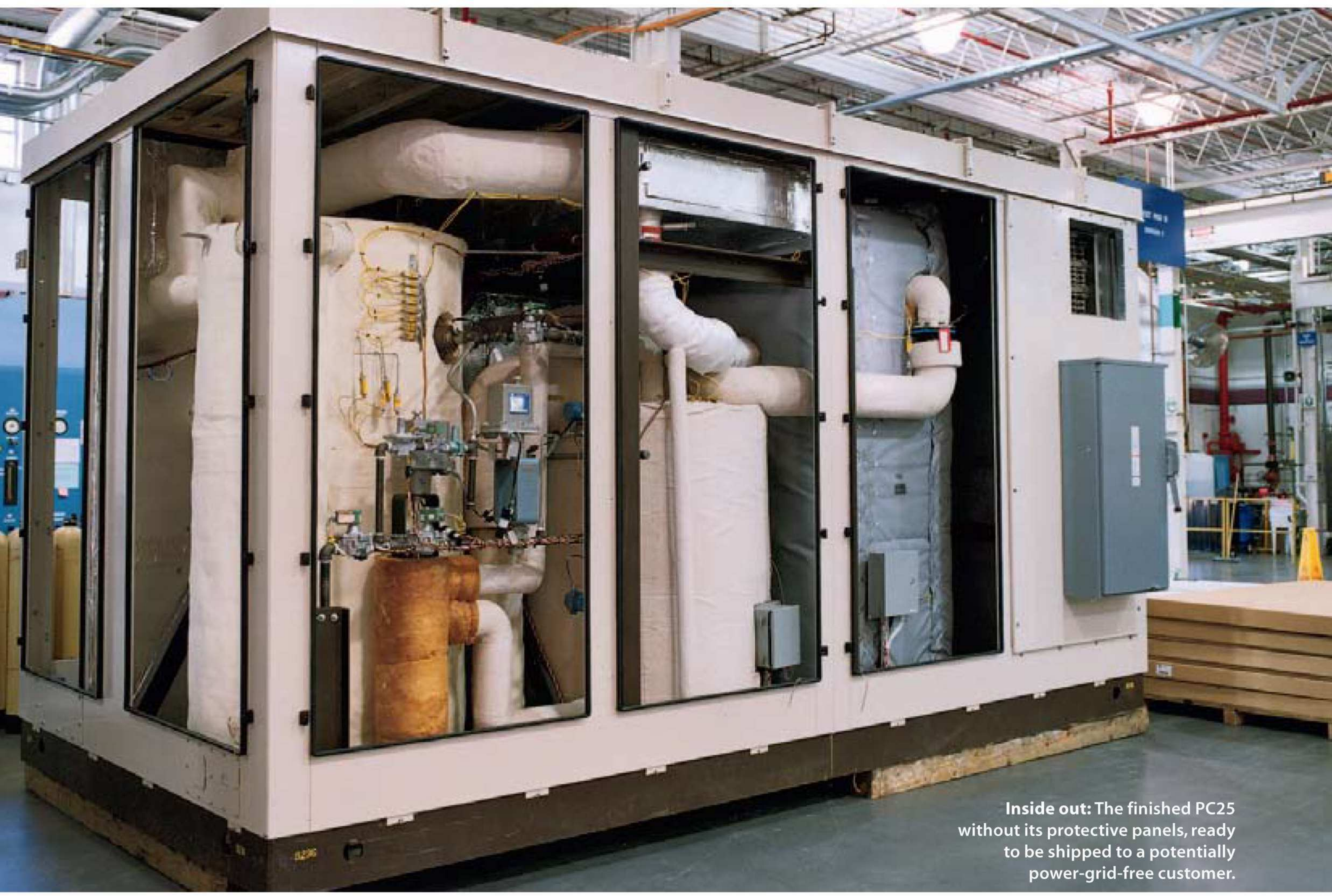
Of course, International Fuel Cells has to first bring its volume up before it can start taking advantage of these opportunities. To do that, the company has focused on potential customers who may be willing to pay a significant price premium in order to capture the fuel cell's advantages. Such customers include those that require an especially reliable source of power—or simply more power than can be had from the utility grid—as well as heat, and don't want to live with the emissions of a gas turbine. "There are applications where paying $4,500 per kilowatt of capacity is a good deal," insists Guy Hatch, director of residential business at the company.

As it turns out, there are plenty such potential customers. Data centers, for example, require a constant, steady source of electricity and typically use a local generator to either smooth out power from the grid or back it up in case of an outage. First National Bank of Omaha in Nebraska installed a set of PC25s after an outage brought down its credit card verification network, costing just one of its customers—The Gap—$6 million in sales. And it's not just computers that need reliable power: the U.S. Postal Service's main facility in Anchorage, AK, decided to go off the grid in favor of PC25s when repeated brownouts lasting as little as a fraction of a second caused its sorting equipment to jam. At the dedication ceremony for the new equipment, a blackout left the surrounding region dark while the facility remained fully operational; the attending dignitaries had to assure observers it wasn't a planned demonstration. Even sites in the hearts of big cities can find utility power unavailable because existing cables have nearly maxed out on their ability to bring more power in. New York is one such city; power inadequacies prompted the Central Park police station to install a PC25 in lieu of marring the bucolic setting with the whine and fumes of a traditional gas turbine. The Condé Nast building in Times Square operates a PC25 on its fourth floor.

The ability to put the fuel-cell-based power generator's waste heat to work is the factor that makes the numbers work out for some purchasers. In addition to helping to warm buildings in the winter, the heat can in hotter months drive a type of air conditioner called an "absorption chiller." First National estimates an annual savings of $200,000 in heating costs and even uses the warm water coming out of the fuel cell to melt ice and snow in its headquarters' plaza. A potential big reduction in home heating and air-conditioning bills is one reason International Fuel Cells, along with Ballard, H Power and other rivals, believes it can get upscale, environmentally conscious homeowners to spring for units that put out about five kilowatts and that might eventually sell for as little as $5,000 or so—though the first units are likely to go for four times that much. "We spoke with one homeowner who had been looking at spending $50,000 for solar panels," says International Fuel Cells' Hatch, who thinks $20,000 for a fuel cell doesn't seem that outrageous in that context.

SOME BELIEVE THAT THE FUEL-CELL-BASED POWER-GENERATION AND CAR MARKETS WILL ULTIMATELY BE HEAVILY INTERTWINED, WITH BOTH GENERATORS AND CARS FUELED FROM THE SAME SOURCE.

How far can these mini power plants scale upward? At least one company hopes to turn out fuel cell generators that compete in price not merely with small gas-turbine generators but with the large generators employed by utilities. FuelCell Energy of Danbury, CT, has eschewed the solid electrolytes employed by virtually every other fuel cell manufacturer in favor of a molten carbonate. The material performs roughly the same function—conducting protons from the negatively charged plate to the positively charged one while repelling electrons. But it enables a simpler process for reforming hydrogen, which makes for a big technical advantage when it comes to mass production. As a result, FuelCell believes it can produce units that turn out up to three megawatts of power and operate at almost 80 percent efficiency. That's better than even the largest central power-generating station can achieve. Plus, the electricity can be produced in the consuming company's parking lot, instead of traveling across miles of power lines that are costly to install and maintain. "Utilities can produce electricity cheaply," says Jerry Leitman, CEO of FuelCell Energy. "But most of the cost is in distributing and transmitting it."



Inside out: The finished PC25 without its protective panels, ready to be shipped to a potentially power-grid-free customer.

HYDROGEN FOR THE MASSES

Even as fuel cell generators get more powerful and efficient, most everyone in the field sees their development more as a means of getting at the potentially enormous market for fuel-cell-powered cars than as a basis for the next-generation power grid. In terms of basic technology, the transition would be a fairly simple one: the same plate-sandwiched membranes that power the electric-generator products can be placed in smaller, relatively lightweight stacks capable of putting out the 50 kilowatts or so needed to power an electric-motor-equipped car while fitting in a trunk or under a back seat. Despite its long interest in electrical-power generation, International Fuel Cells, for one, is quite open about using the field as a stepping stone to the lusted-after car market. "Transportation is obviously an attractive target, and power generation applications are part of the path there," says head of manufacturing Bolch. The company has already worked with BMW to produce a car that operates in part off its fuel cells, and with Hyundai to develop an all fuel-cell-powered car—and it claims to be in talks with at least four other major car manufacturers. It has also struck deals with Thor, a leading manufacturer of shuttle buses in North America, and Irisbus, a major European bus producer.

Commercially viable fuel cell cars remain years away, though, and may be decades off without a breakthrough in the battle to bring costs down. Right now, says Stroh, even mass-production economies wouldn't allow fuel cells to come close to the price of internal-combustion engines, which sell for about $50 per kilowatt of power-generating capacity—beating fuel cells by a factor of about a hundred. "The cost of materials alone would make them far too expensive," Stroh says.

Perhaps that's why some experts believe that the fuel-cell-based power-generation and car markets will ultimately be heavily intertwined, with both generators and cars fueled from the same sources. The Rocky Mountain Institute's Swisher envisions a scenario in which employees at industrial sites with fuel-cell power generators will fill their fuel cell cars up with hydrogen while at work—and even use their parked cars as supplemental power generators. "The ability to interconnect fuel cell facilities would be a catalyst in the market," he says, eventually leading to similar applications for homeowners.

The ultimate result? Looking further out, it's not hard to conjure up images of a full-fledged hydrogen economy, in which fuel cells power everything from laptop computers to airplanes and bicycles; indeed, experimental versions of all three are already under development. What's more, if every home, business and community operates power-generating fuel cells, then it might make sense to link them all together in a massive national power grid, perhaps controlled via the Internet, so that surplus energy at any location can be spontaneously transferred to those locations suffering shortages.

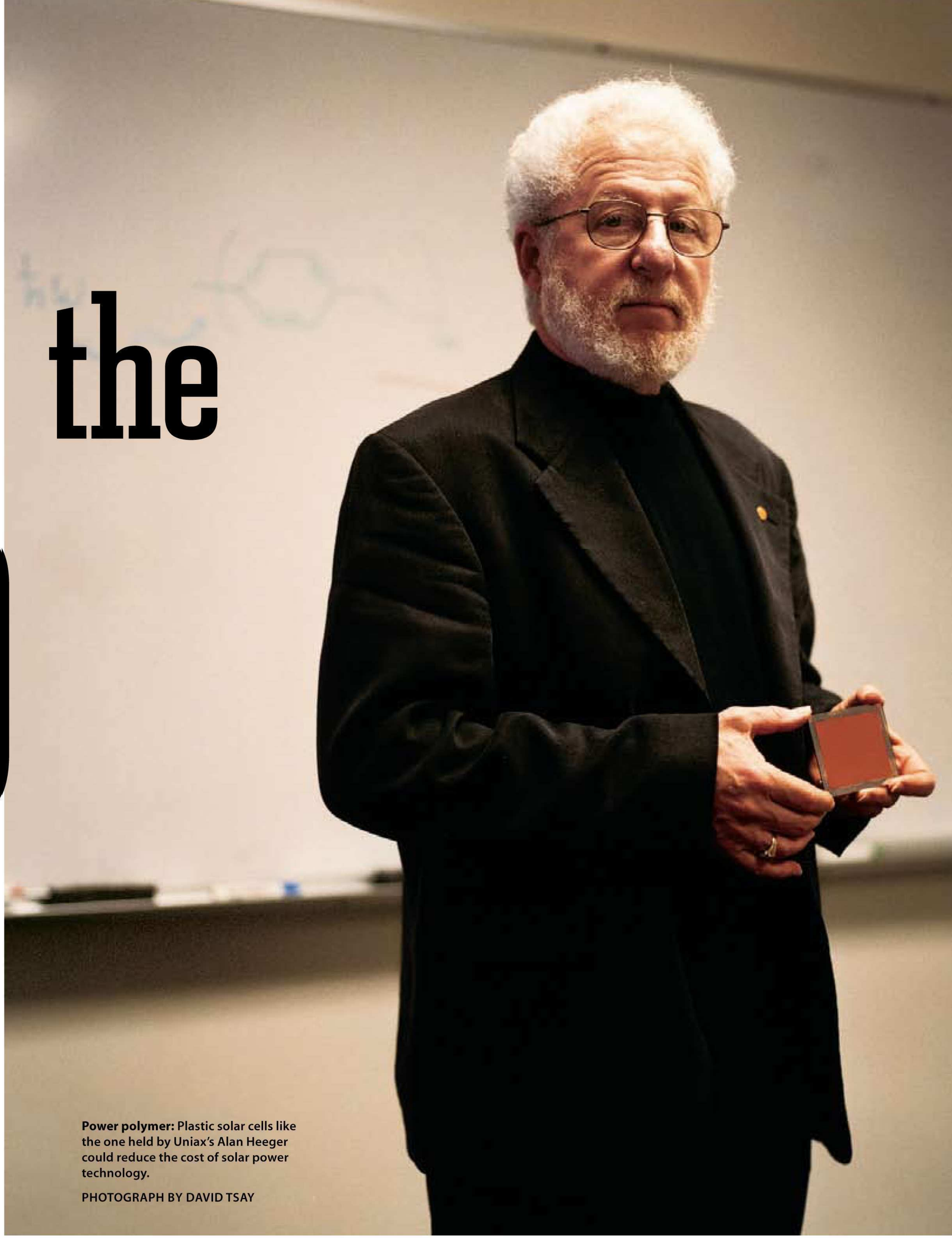
Of course, as Stroh points out, even if no one obstacle to a hydrogen economy seems technically insurmountable, countless smaller ones still need to be overcome. But given that hydrogen makes up 75 percent of all known matter and is the fuel of stars, maybe the universe is trying to tell us something. TR

BY PETER FAIRLEY

solar on the cheap

ONE OF THE CLEANEST ENERGY SOURCES AROUND IS GETTING CHEAPER. THANKS TO NEW MATERIALS, SOLAR CELLS COULD SOON BE UBIQUITOUS.

During his Nobel Lecture at Stockholm University in Sweden, Alan Heeger pulled out a personal digital assistant and held it up so the crowd could marvel at its brilliant display screen. Heeger shared the 2000 Nobel Prize in chemistry for the materials that made this screen possible: electrically conductive plastics. What he didn't hold up, though, was an application of those same new materials that could have a far greater impact. Instead of conducting electricity and emitting light, as they do in flat-panel displays, these same plastics can be made to run the reverse process, absorbing light and producing electricity. If they work, they could fulfill the dream of many energy researchers: inexpensive solar cells.



Power polymer: Plastic solar cells like the one held by Uniax's Alan Heeger could reduce the cost of solar power technology.

PHOTOGRAPH BY DAVID TSAY

Rooftop laborers: Cheap thin-film solar panels from Energy Photovoltaics are already generating power in California homes.

PHOTOGRAPH BY ANGELA WYANT

Such materials could change the face of solar power because plastic is cheap, and cheap would be a rather novel and welcome way to describe solar technology. The advantages of solar power are obvious: every minute, the sun pounds the surface of the earth with more energy than the entire world consumes in a year—a potential source of virtually unlimited, clean and free electricity. But until recently the high cost of the materials used in solar cells has relegated the technology to powering satellites, high-tech backwoods cabins and communications towers beyond the reach of power lines. Solar cells made from materials like electrically conductive plastics could finally make solar power affordable for far broader uses. Moreover, says Heeger, the chemistry behind these plastics is rather simple, so they could be fairly easy—and cheap—to manufacture.

Conventional solar cells cost so much because most are made from the same relatively expensive silicon semiconductors used in computer microchips. Recently, manufacturers have found ways of making solar cells using ultrathin films of silicon; consequently, solar power is getting cheaper and consumption is increasing. More than 200,000 homes in the United States now derive at least some of their power from solar cells; the technology is already paying its way in places like California, where energy is expensive and governments are willing to subsidize solar power to make it competitive with fossil fuels.

But switching to thin-film silicon may not bring about the drastic cost reductions solar cells need to effectively compete with coal-, oil- and natural-gas-generated electricity across the globe. Despite nearly quadrupling in sales over the last five years, solar still accounts for only .04 percent of worldwide power generation. What is needed to accelerate the penetration of solar power is even cheaper materials. And an increasing number of companies are looking to electrically conductive plastics and other novel organic materials as the solution.

Researchers developing these new-age materials for solar cells are sensitive to failed promises about solar power and caution that organic solar cells could be a decade or more from the market. At the same time, they are clearly excited about recent advances in the materials which, if sustained, could deliver the performance and affordability that will render solar power ubiquitous. "If the performance of organic solar cells was as good as conventional ones, it would be pretty darn interesting," says Princeton University electronics expert Steven Forrest. "That could be a huge market."

THINK THIN

Solar cells, technically referred to as photovoltaics, take advantage of the same electronic properties that make semiconductors so vital to the computer industry. When sunlight strikes the sur-

face of a semiconductor, the photons transfer their energy to electrons in the material; in a working solar cell that energy is captured and put to use. A sheet of semiconductor material lies sandwiched between two layers of electrode material. A built-in electric field draws the excited electrons to the top electrode, which carries them out of the cell and into a circuit. The bottom electrode gathers electrons from the circuit to fill the "holes" that the excited electrons left behind. The bottom line is that the semiconductors transform sunlight into usable electricity.

But most of the solar panels sold today employ crystals of silicon that are expensive to manufacture. Silicon crystals may justify their cost in microprocessors, but they price solar power out of a market dominated by cheap fossil fuels. "If you want to compare purely on a dollar per watt basis, solar power is three to four times more expensive right now," says Atul Arya, chief operating officer with Linthicum, MD-based BP Solar, a subsidiary of the large oil company and one of the world's top producers of silicon solar cells.

Increasingly, the search for low-cost technology is leading BP Solar and other solar-cell manufacturers to abandon silicon crystals altogether. In its place, these firms and half a dozen startups are developing photovoltaics employing cheap amorphous silicon, and even semiconductor alloys, that can be quickly spread into a thin film just a few thousandths of a millimeter thick—about a hundred times thinner than the silicon crystals used in conventional solar cells. Because these thinner solar cells require less semiconductor material and are amenable to mass production, they are significantly cheaper. And while these types of semiconductors lack the electron-shuttling efficiency of silicon crystals, they compensate by absorbing more photons than silicon crystals.

Ken Zweibel, who leads thin-film development at the Golden, CO-based National Renewable Energy Laboratory complex where many of the technology advances are being made, predicts that thin films will deliver highly efficient solar cells at one-quarter to one-fifth the cost of today's cells. Cheap, thin films of amorphous silicon or alloy that can capture as much as 20 percent of the sun's energy (researchers can now make films in the lab with 18 percent efficiency) could make solar cells practical for homeowners, not just in sunny California, where clogged power lines deliver the country's most expensive electricity, but in Boston, Chattanooga and Tampa Bay.

The low cost and inherent flexibility of these thin solar cells also means they can be easily applied as coatings on a range of materials, including glass and roofing tiles. To demonstrate this aspect of the technology, BP has installed translucent awnings embedded with thin-film photovoltaics at 250 of its gas stations around the world, keeping customers dry while powering the pumps. "It becomes a window pane, or it could be a shading application, or it could be a skylight application. We are doing all of those," says BP's Arya.

Despite such promise, however, it could take decades for thin films to transform solar power from a marginalized technology to a mainstream source of energy. Steady growth at today's impressive rates, doubling the market every three years, will only bring the industry to 10 percent of peak power generation in 2030, according to a U.S. solar-power industry road map issued last year. What is needed to accelerate the penetration of solar power is photovoltaic materials that are really cheap—cheap as plastics.

POWER PICTURES

Carbon-based materials such as Heeger's polymers could steal markets away from conventional semiconductors because they can be applied in even thinner layers and, in theory at least, could lead to simpler and less expensive manufacturing processes. For example, they can be dissolved to produce a photovoltaic ink, which an ink-jet printer could squirt in a thin film on a variety of surfaces.

The underlying technology has been around for years: researchers at Eastman Kodak created the first organic solar cells during the energy crisis of the 1970s. Kodak was already churning out vast quantities of photographic film containing light-absorbing organic dyes and figured it could adapt those dyes to capture energy instead of images. The project fell to Ching Tang, a physicist fresh out of graduate school. Tang struggled for four years and nearly gave up before a breakthrough in 1979, when he borrowed a set of organic pigments developed for other purposes by Kodak's chemists and layered them to mimic the arrangement of electron-shuttling semiconductors in conventional photovoltaics. While these first organic solar cells could convert only one percent of the sun's energy into electricity, they showed promise for improvement.

But Tang kept his success quiet until 1987, because Kodak was close to developing other commercial uses for the proprietary pigments and forbade him from publishing his results. By the time he did, the energy crisis had passed and

Playing the Sun

A sampling of companies developing new thin-film and organic solar cells

COMPANY	LOCATION	TECHNOLOGY	MATERIALS
BP Solar	Linthicum, MD	Thin film	Amorphous silicon, cadmium telluride
Energy Photovoltaics	Princeton, NJ	Thin film	Amorphous silicon, copper indium gallium diselenide
Siemens Solar	Munich, Germany	Thin film	Copper indium diselenide
Cambridge Display Technologies	Cambridge, England	Organic	Pigments and organic liquid crystals
DuPont Displays' Uniax	Santa Barbara, CA	Organic	Polymers
Global Photonic Energy	Ewing, NJ	Organic	Pigments and fullerenes
Quantum Solar Energy Linz	Linz, Austria	Organic	Polymers and fullerenes

Kodak was onto a seemingly more enticing opportunity: using Tang's layered structure to turn similar pigments into organic light-emitting diodes for flat-panel computer displays *(see "A Bright Future for Displays,"* TR *April 2001)*. For over a decade, Kodak and its competitors nurtured this technology, which is now poised to take a piece of the $25 billion-per-year flat-panel market, while organic solar cells were forgotten.

With yet another energy crisis looming, however, organic solar cells are enjoying a renaissance. After two decades stuck at Tang's one percent power output, researchers are succeeding in pushing the boundaries of organic solar cells' performance, and investment in the field is soaring. Recently, research groups produced solar cells that can convert two to 4.5 percent of the energy in sunlight to electricity. They are bullish about matching the power of the low-end thin-film photovoltaics in as little as three years. "We're creeping up on amorphous silicon and there's no reason to believe that we couldn't do as well as crystalline silicon," says Princeton's Forrest.

Uniax, a company cofounded by Alan Heeger and acquired by DuPont two years ago, is taking a somewhat different tack, developing solar cells using polymer blends. And rather than immediately adapting the polymers to make solar cells for powering entire homes, Uniax is first testing the materials as photodetectors in imaging devices like scanners and digital video cameras. Photodetectors consist of arrays of millions of tiny solar cells; the cells reconstruct images by creating electrical currents proportional to the intensity of light shining on them. Each cell represents one pixel of information. Heeger says Uniax has already developed polymer-based photodetectors that rival the sensitivity of commercial photodetectors, which employ standard semiconductors. And unlike conventional devices, plastic photodetectors can be built to larger scales, say for flexible sensors that capture images from sheets of paper without scanning, or still larger detectors for rapid medical imaging.

Manufacturing the plastic solar cells could be relatively quick and easy. Heeger envisions using ink-jet printers to spray a series of films on a surface—the organic semiconductors, electrodes and protective coatings—to fashion a photodetector. And fabricating large devices for power generation could be even simpler, since the light-absorbing films do not need to be divided into pixels. "Making large areas of a thin film from these organic semiconductors in solution is straightforward. That's why it's attractive," says Heeger.

First-generation organic solar cells could begin to enter the market in the next five to 10 years through applications like Heeger's photodetectors, or alternatively through ultra-low-margin products such as solar-powered musical cards and other disposable electronics. Then they could tackle small electronic devices, such as solar-powered calculators and toys.

But to ready organic solar cells for the rooftop, developers must overcome the material's ultimate weakness: its fragility. The light-sensitive organic molecules under development for use in photovoltaics break down when exposed to oxygen. Will they ever be ready to bake under the sun day in, day out for several decades and still generate electricity? Kodak's Tang says the question reminds him of his own early doubts about organic light-emitting diodes. He says he wondered 15 years ago why anyone would bother trying to make a device out of this highly unstable material. Today he marvels at the colorful organic displays entering the market.

What Tang couldn't see 15 years ago was that solar cells could be encapsulated with a polymer similar to Teflon that is all but impervious to the elements and provides a hermetic seal for the fragile organics. Encapsulated organic solar cells could already provide the several thousand hours of working life required of a solar-powered calculator or digital video camera, and the materials' utility could be extended to the hundreds of thousands of working hours required for providing buildings with electrical power.

Kodak is no longer pursuing the idea of organic solar cells, but Tang dreams of returning to research that could help make them a reality. While beautiful displays may be more lucrative in the short term, Tang says the challenge of replacing fossil fuels is more pressing. "People can do without television," says Tang, "but you cannot do without energy." TR

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Basking in the sun: Zoltan Kiss of Energy Photovoltaics showcases his company's latest solar panels made of thin-film silicon solar cells.

PHOTOGRAPH BY KYOKO HAMADA

BY DAVID TALBOT

THE NEXT NUCLEAR PLANT

PHOTOGRAPH BY LOUISE GUBB

The first commercial pebble-bed reactor—small, efficient and immune to meltdown, say proponents—is proposed for South Africa. The U.S. may be next.

Out of Africa: David Nicholls, CEO of Pebble Bed Modular Reactor, stands at an existing nuclear power plant in Koeberg, South Africa, possible site of the first commercial pebble-bed nuclear reactor.

Except for the genets, caracals and other exotic wildlife ranging in the surrounding nature preserve, the pair of nuclear power reactors at Koeberg, South Africa, look much like their squat, domed counterparts dotting the United States. The basic technology is the same: beneath steel-reinforced concrete domes, the fission of uranium fuel generates turbine-driving steam.

Just like the United States, South Africa is also weighing difficult choices about how to meet future energy needs. The African nation doesn't have much hydroelectric or natural-gas capacity. Coal is plentiful but dirty to mine and burn—and most of it is located too far from coastal population centers to make economic sense. And as in the U.S., many in South Africa believe nuclear power has a place in the future mix.

But there's a key difference. So far, Washington is only talking about a nuclear rebirth; South Africa is getting ready to build. And Koeberg, on the Atlantic coast about 30 kilometers north of Cape Town, is emerging as the epicenter of a technology initiative that sponsors claim could usher in a new era of safe, inexpensive nuclear power using a long-studied and promising design: the pebble bed modular reactor. A construction decision by an industrial consortium is expected sometime this year. South Africa's regulatory apparatus will get final say, but momentum behind the proposal is remarkably strong. "I believe that we will resolve all issues outstanding and this will get built," says David Nicholls, CEO of the consortium, Pebble Bed Modular Reactor.

The consortium says the technology—rooted in research and prototype reactors that date to the 1960s—has matured to the point of achieving the twin goals that have eluded the nuclear industry in the post-Three Mile Island and Chernobyl era: affordability and inherent safety. First, a pebble bed reactor is relatively simple to build and inexpensive to operate; the consortium says construction and operating costs are expected to be "competitive" with those of coal and natural-gas plants. Second, and perhaps more crucial, they say, it is immune to today's worst-case scenario: a loss of coolant in the reactor core that would lead to a melting of uranium fuel and a catastrophic release of radiation. That's because the fuel is encased in billiard-ball-sized graphite "pebbles" that can't get hot enough to melt. What's more, this encasement may make the spent pebbles more rugged in long-term storage.

The fuel design isn't the only thing that makes this reactor fundamentally different from the more than 430 commercial nuclear power reactors worldwide, nearly a quarter of which are in the United States. The pebble bed reactor is cooled with helium gas instead of water, operates at higher, more efficient temperatures and—thanks to the inherent safety claimed by its builders—dispenses with the containment dome and regional evacuation plan now required of U.S. nuclear facilities. Individual pebble-bed plants would also have a smaller footprint than today's plants and produce a mere 100 megawatts or so of electrical power—a tenth as much as today's typical nuclear behemoth. This modest scale limits the early financial losses many large plants incur by initially glutting the market with electricity, and gives utilities the option of building just what's needed at first and then adding units later if demand warrants it.

Though pebble beds have advocates in utility boardrooms, their case is not yet proved in the eyes of the U.S. Nuclear Regulatory Commission. The agency hasn't signed off on the safety of any of the plant's features, from the fuel design to the lack of containment. And these reactors don't solve the same two basic problems that dog the entire nuclear industry: they create highly radioactive fuel waste and are potentially vulnerable as terrorist targets. Nevertheless, the South African partners believe they can resolve regulatory questions and bring a pebble bed juggernaut to the United States. The consortium includes not only the South African government's utility and industrial agency but also Chicago-based utility conglomerate Exelon and British Nuclear Fuels, owner of Pittsburgh-based reactor builder Westinghouse Electric. Already, Exelon is the largest U.S. nuclear-plant operator; its 17 reactors include the still-operating reactor at Three Mile Island near Harrisburg, PA, whose twin partly melted down in 1979, crippling the nuclear industry.

Exelon in particular sees pebble bed technology as the breeze blowing the nuclear industry out of its doldrums. Though it hasn't yet made a construction proposal in the United States, the company envisions erecting clusters of pebble beds next to existing nuclear plants. "It is considered a very safe technology; it is relatively simple, it's very efficient," says Jim Muntz, vice president for nuclear projects. Asked whether Exelon wants to construct a pebble bed reactor in the United States, he answers unabashedly, "We want to build 40 or 50 of these. This isn't about building one; this is about building a lot of them."

PEBBLES' PROGRESS

Like today's commercial nuclear power plants—which produce about 20 percent of U.S. electricity—the pebble bed reactor uses uranium as its power source. Under the right conditions, uranium atoms split, or "fission," throwing off energetic neutrons and other particles that break up still more uranium atoms in a chain reaction that generates enormous amounts of heat. In today's plants, the heat boils water to create steam to drive turbines and create electricity. In the pebble bed reactor, the nuclear reactions heat helium gas, which spins turbines as it expands.

The more fundamental departure from conventional nuclear design, though, rests in the physical configuration of the uranium fuel. Today's reactors use uranium pellets embedded in metal rods and bathed in cooling water. In contrast, the pebble bed's fuel kernels are encased in billiard-ball-sized graphite pebbles filling a doughnut-shaped reactor core lined with graphite *(see "Heart of the Pebble Bed Reactor," p. 57)*. The graphite lining "moderates" the nuclear reaction, slowing neutrons and reflecting them back to the pebbles to keep the fission process humming. (In conventional reactors, the cooling water doubles as the moderator.)

While the pebble bed reactor has yet to make its commercial debut, the design isn't new. Over the past four decades, nuclear engineers have been tinkering with gas-cooled reactors, some using pebbles, with varying degrees of success. Early gas-cooled plants operated in Pennsylvania (Peach Bottom 1, in service from 1967 to 1974) and Colorado (Fort St. Vrain, 1974 to 1989) but encased the kernels in stationary graphite blocks. The West German government spearheaded the pebble concept, funding one prototype that operated from 1966 to 1989, as well as an updated ver-

sion that opened in 1983 near Hamburg. The new plant, though, suffered from design flaws; its boron carbide control rods occasionally smashed fuel pebbles, and some of the reactor's gas ductwork broke, leading to shutdowns and poor efficiency. Amid hard economic times for nuclear power and worldwide safety fears brought on by the April 1986 disaster at the Soviet Union's Chernobyl nuclear reactor, West Germany decided in 1990 to shut the plant rather than fix it. But in 1999, the South African utility licensed the German technology. The utility says it has eliminated the flaws that plagued the German reactor and is now resolving final design details.

The South Africans were not alone in seeing value in the technology. In 2000, the Chinese government began operating a small, 10-megawatt pebble bed research reactor, also based on the German design. And in recent years, a research program has grown up around the concept at MIT. The two decades of German operating experience "formed the basis for our feeling that this would actually work," says nuclear engineering professor Andrew Kadak. "The fundamentals of the technology were thoroughly demonstrated." In 1998, Kadak joined fellow MIT nuclear engineering professor Ronald Ballinger in launching a next-generation pebble bed design, one Kadak says was developed from the public record and from the freely shared experience of pebble bed researchers. The MIT design calls for standardized, readily replaceable parts that Kadak says should make the plants easier to build and less expensive to maintain than the South African version.

Whatever upgrades might come to pebble bed, though, none will solve the question of what to do with waste. Resolution of this issue may prove decisive for the future of any reactor technology. Spent fuel is dangerously radioactive for 10,000 years, and all fuel waste from the nation's existing nuclear plants remains stored at the plants themselves, awaiting the federal government's decision on opening a repository at Nevada's Yucca Mountain or elsewhere *(see "Whose Nuclear Waste?" p. 60)*.

The design of the pebble bed fuel, though, may provide at least a partial solution. Kadak believes that the silicon carbide and graphite coatings will stand up better over the millennia than the zirconium-alloy jackets of conventional fuel rods. He says that some studies show that the pebbles would provide excellent

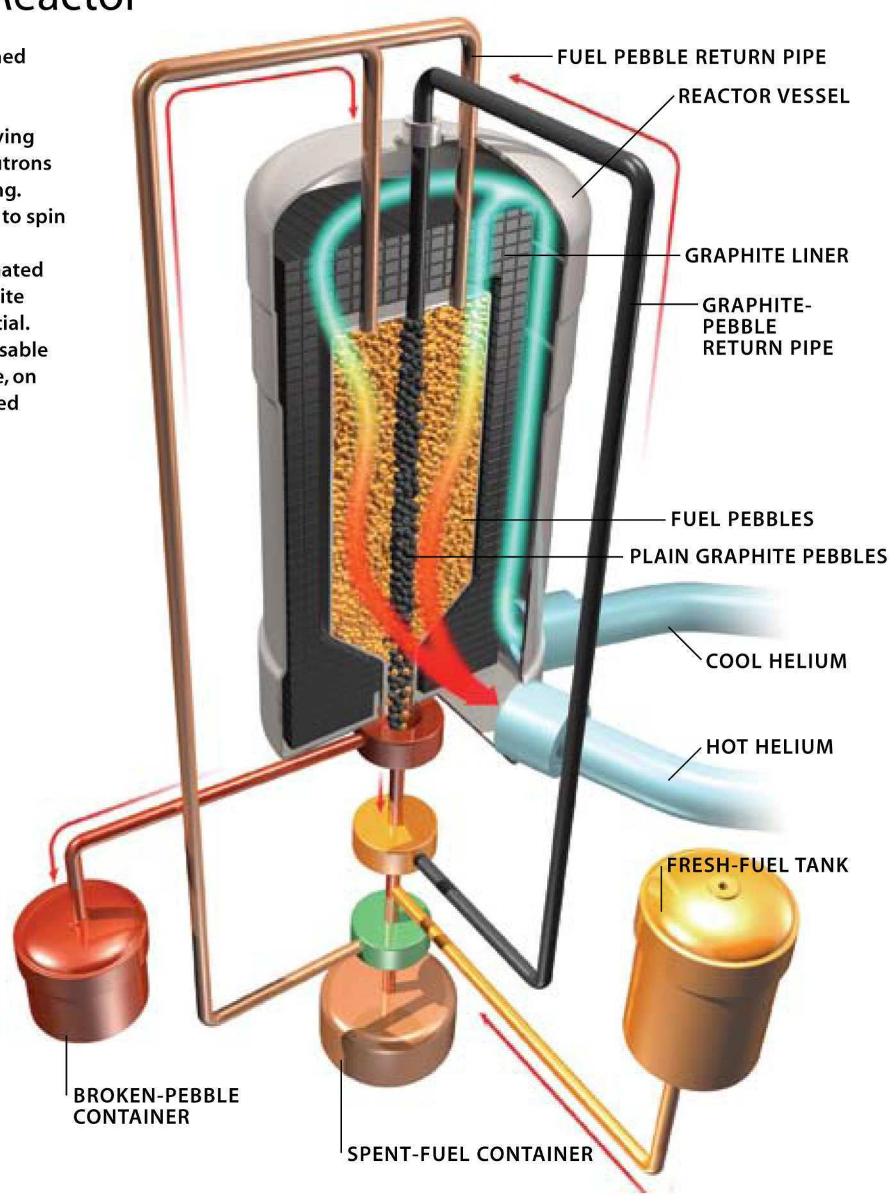
Heart of the Pebble Bed Reactor

In a pebble bed modular reactor, uranium fuel contained inside graphite "pebbles" slowly flows, gumball-style, through a helium-cooled reactor lined with graphite.

The lining, along with plain graphite pebbles moving through the center, reflect and slow the uranium's neutrons to keep the energy-producing fission process humming. Helium heated by the energetic fuel pebbles expands to spin a turbine (not shown), which generates electricity.

As pebbles flow out of the reactor bottom, automated systems discard broken pebbles and send plain graphite balls back to the top, propelled by a pressure differential.

Intact fuel balls are checked for power levels. Reusable fuel is sent back to the reactor—a trip that it will make, on average, ten times in three years. Spent fuel is discarded into a container and replaced with fresh fuel.



Small Pebbles, Tiny Kernels

In the reactor core, 330,000 billiard-ball-sized graphite fuel pebbles (top) each contain 15,000 sand-sized (about one-millimeter) fuel kernels (bottom).

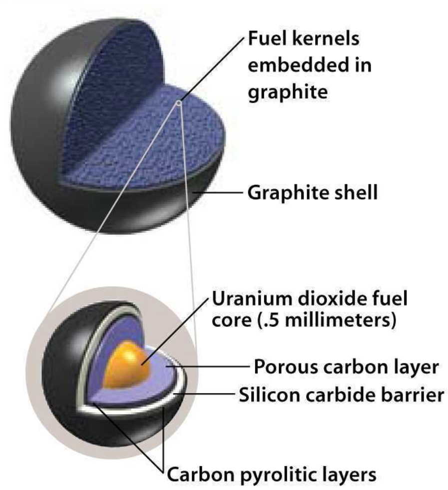


ILLUSTRATION: SLIM FILMS; SOURCE: EXELOR

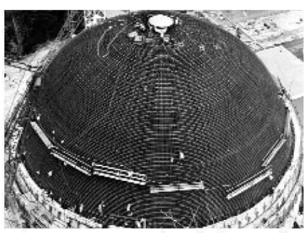
Nuclear-Power Timeline

1942 In the first demonstration reactor (the Chicago Pile 1), Enrico Fermi uses uranium fuel and graphite moderation to produce the first controlled nuclear chain reaction.

1954 The U.S. Navy launches the first nuclear-powered submarine, the USS Nautilus, whose pressurized-water reactor is the basis for many later commercial power designs.

< 1955 Arco, ID, becomes the first U.S. town to receive its entire supply of electricity from nuclear power. The source: an experimental boiling-water reactor called the Borax III.

1957 In Shippingport, PA, the first full-scale nuclear power plant in the U.S. begins operation, with a 60-megawatt reactor, scaled up from the navy's nuclear-sub design.



>1960s-1970s Prototype reactors using helium coolant and graphite moderation are built in Colorado and Pennsylvania; however, water-cooled reactors (like this one, built in Wiscasset, ME, in 1972) dominate worldwide.

1979 In the worst U.S. nuclear accident to date, a pressurized-water reactor at Three Mile Island, near Harrisburg, PA, undergoes a partial meltdown. The event triggers new safety regulations and stalls the nuclear-power industry.

^1986 A reactor at Chernobyl, in Ukraine, overheats, explodes and burns, releasing massive amounts of radiation. The accident kills 35 people immediately, forces 135,000 to evacuate the region, and leads to an increase in thyroid and other cancers.

Late 1990s Advanced pressurized- and boiling-water reactors with "evolutionary" improvements are built or planned in Japan, Taiwan and South Korea. U.S. regulators approve three such designs, which are more efficient and have new safety systems, like gravity-fed emergency water cooling tanks.

2001 Updating the German pebble-bed design, South Africa's state power utility, together with U.S. and British partners, nears a final decision on building a pebble bed modular reactor north of Cape Town.

resistance against the chief nemesis of long-term storage: corrosion from water. "We don't need a 10,000-year container, because we've already got it in the ball," Kadak asserts.

No matter how rugged such pebbles may be, they'll still require long-term storage, says Richard Lester, another MIT nuclear engineering professor and director of the school's Industrial Performance Center. And the same layering that provides protection also adds volume to the waste, requiring a larger repository. Finally, he adds, no amount of shielding can protect the industry from public fears. "I don't think it's the case," he says, "that a nuclear-waste repository will be more acceptable to folks who live in the area because you've got pebbles."

HOW SAFE?

The growing interest in the pebble bed design comes amid changes in the U.S. regulatory apparatus designed to make it easier to build and operate nuclear plants of any approved type. The Nuclear Regulatory Commission has reduced bureaucratic obstacles to nuclear plants by allowing for a combined construction and operating license. This eliminates the two-step process that produced the debacle in Shoreham, NY, where a nuclear power plant was fully built but never allowed to operate because of fears the region's population couldn't be evacuated in case of accident. The regulatory commission also has begun approving new reactor designs. In recent years, it has signed off on upgraded versions of existing water-cooled designs said to be significantly simpler, safer and more efficient than their predecessors. Regulators and Exelon have already begun preliminary reviews of the safety of the pebble bed design.

While the commission has taken steps to clear the near-term path for nuclear-plant construction, the U.S. Department of Energy is honing the long-term vision. The DOE is creating an $8 million technology road map, surveying more than 100 conceptual designs—reactors that use molten lead as a coolant, for example, or that employ molten uranium instead of solid pellets as fuel. The agency's goal is to select, by the beginning of 2003, a handful of promising designs—and then dole out R&D funding to make them deployable by 2030. The DOE wants the designs to be safer and more efficient than those in use today and hopes that they can transform the industry's image. "One of the things the public sees in nuclear power is a technology that requires them to evacuate their homes in case of an accident. For the next generation to be successful, those precautions need to be obviated by technology," says William Magwood, director of the DOE's Office of Nuclear Energy, Science and Technology.

One promising design, similar to pebble bed, is under development by San Diego-based General Atomics. As in the early gas-cooled U.S. prototypes, nuclear fission occurs in coated uranium kernels embedded in stationary graphite blocks; helium transports the heat away to spin a turbine. General Atomics is working with Russian authorities to build a prototype in Tomsk, Russia, which would burn plutonium from old Soviet weapons stockpiles. But this project hasn't progressed to the detailed design stage, and no utility has yet discussed building such a reactor in the United States, says Walter Simon, General Atomics' senior vice president for reactor projects.

Back on U.S. soil, two utilities—Richmond, VA-based Dominion and Entergy of New Orleans—have approached the Nuclear

TIMEPIX (CHERNOBYL); HULTON/ARCHIVE (WISCASSET REACTOR); TIMEPIX (ARCO CONSOLE); AP PHOTOS (SUB)

Regulatory Commission to discuss the feasibility of building new reactors alongside existing U.S. nuclear plants (though neither company has indicated what type of reactor it might want to build). This push to market is well timed, says Ted Marston, vice president and chief nuclear officer at the Electric Power Research Institute, a Palo Alto, CA-based R&D organization funded by utilities. Trends in energy demand and power plant development costs could make nuclear power competitive, Marston says. "We believe there is an opportunity for significant new nuclear deployment around 2010." And pebble bed reactors could lead the charge. Compared with conventional water-cooled reactors, says Marston, gas-cooled systems "are available in smaller sizes, higher efficiencies, and can be installed in increments." They're more efficient largely because they operate hotter than water-cooled reactors; the higher the temperature, the less energy is wasted.

But while Exelon says these efficiencies could make pebble beds 20 percent cheaper to build than conventional nuclear plants, the safety of pebble bed reactors remains unproven, in the view of U.S. regulators. The Nuclear Regulatory Commission and nuclear-industry critics are especially leery of the pebble bed's paucity of containment and safety systems known in the nuclear industry as "defense in depth." The pebble bed plant lacks a thick, reinforced containment dome designed to withstand the extremely high pressures and temperatures that might result from an accident, and it lacks some of today's backup systems. Similarly, the pebble bed architects propose that their plants wouldn't require regional emergency planning and evacuation programs.

Pebble bed proponents see this as a move toward simplicity and cost-effectiveness. But that is exactly what worries skeptics—and has prompted regulators to ask tough questions. "Right now, the concern with pebble bed would be the reduced number of barriers," says Ashok Thadani, director of the regulatory commission's Office of Regulatory Research. "Why is that okay? Why should we support that? We need a much more thorough understanding of the fuel behavior and its failure points."

Reaching that understanding is an active quest within Thadani's agency. Officials there don't yet have answers to some basic questions—a situation both sides hope to resolve by December 2002, after which Exelon says it would quickly seek formal design and construction approvals. The agency has asked Exelon to explain, for example, how it calculates that no containment is needed, how the fuel's integrity will be assured and what would happen if moisture or air entered the reactor.

These questions have some unacceptable answers, say some nuclear-power skeptics. "The lack of defense in depth is an irresponsible approach to public safety," says Edwin Lyman, a physicist at the Nuclear Control Institute, a nonprofit research and advocacy center in Washington, DC. "There is simply not enough known about the way the reactor is going to operate." Lyman and his counterparts at another watchdog group, the Cambridge, MA-based Union of Concerned Scientists, say a pebble bed reactor might be vulnerable to catastrophic fire. As long as helium bathes the graphite, fire is impossible. But if sufficient air enters and creates a draft, the carbon-based graphite could burn. Water could make things even worse, intensifying the nuclear chain reaction and creating more heat.

Not to worry, say pebble bed advocates. They maintain that, while entry of air and water could theoretically create a fire, those conditions would be very difficult to produce. MIT's Kadak says the reactor vessel and its cooling system would have to be breached in two places, creating in essence a chimney that would allow a high-velocity stream of air to enter—a scenario he considers highly unlikely. In case of a major break in the vessel, he contends, it would take between 40 and 80 hours for temperatures to rise sufficiently—and more importantly, for air to enter—before fire would be a concern. In a water-cooled reactor, by contrast, a total loss of coolant can produce dangerous heat levels in just a minute or two. According to Kadak, German experiments have shown that, even if the pebbles burned, the fuel kernels within would protect the uranium from dispersion.

"This isn't about building one pebble bed reactor. This is about building a lot of them. We want to build 40 or 50 of these."

BURNING QUESTIONS

But no matter how unlikely a fire might be, its mere possibility is a good reason to require pebble bed plants to have the same thick, expensive containment structures as today's plants, counters David Lochbaum, a nuclear safety engineer with the Union of Concerned Scientists. "We're not sure this reactor will be fireproof as well as meltdown proof," Lochbaum says.

These questions have taken on extra urgency since the September 11 terror attacks. U.S. nuclear plants are not designed to withstand the kind of impact and fire that destroyed the World Trade Center, and MIT's Lester says common sense indicates such an event could cause a catastrophic radiation release at any nuclear plant, no matter what the design. Regulators won't discuss—or don't know—the specific vulnerabilities of nuclear plants, or how pebble bed compares with other designs. "It's very difficult to answer that question," says regulator Thadani. "We are looking, top to bottom, at the operating reactors. We would have to take those factors under consideration if we were to consider a pebble bed, but it's too soon to say." In one sign of how seriously the Nuclear Regulatory Commission views this threat, the agency shut down much of its Web site after September 11 to review whether to purge sensitive information from public view. Exelon says a pebble bed reactor is small enough that the reactor could be two-thirds underground for greater protection.

Ultimately, economics will be the prime driver behind any new push for nuclear power. For now, anyway, it remains cheaper to build and more profitable to operate a natural-gas power plant than one that uses uranium pebbles and helium. "Where the rubber hits the road is when a commercial entity is willing to make an advance payment, and when it starts the siting process," Lester says. "That's when things really start to get serious."

That hasn't happened yet in the U.S. But in South Africa, the pebble bed design is already competitive, says Nicholls, CEO of the South African consortium. Similar benefits, he contends, could be reaped worldwide. "There's $100 billion spent per year on new power stations" around the globe, Nicholls says. "If we only get five percent of that market, that is very exciting." And so, amidst a scenic nature preserve edging the Atlantic coast of South Africa, things are starting to get serious indeed.

BY GARY TAUBES

WHOSE NUCLEAR WASTE?

THE FEDERAL GOVERNMENT AND THE STATE OF NEVADA ARE AT LOGGERHEADS OVER PLANS TO STORE THE NATION'S NUCLEAR WASTE IN YUCCA MOUNTAIN. THE SOLUTION MAY BE TO START ALL OVER AGAIN—AND DO IT RIGHT. PHOTOGRAPHS BY JAN STALLER

If you've never lived in Nevada, it's easy to imagine Yucca Mountain as very close to the middle of nowhere. To get there from Las Vegas, you have to drive northwest into the desert for two and a half hours. At the intersection of Routes 95 and 373, you take a right into the Nevada Test Site, where the government conducted nuclear bomb tests, and pass through a security gate. You then drive another 30 kilometers past Little Skull Mountain and through Jackass Flats, until you come to a small sign that says "Top of Yucca Mountain," at which point you turn left onto a gravel road and head upward.

At the top, you'll find two concrete benches, a rusty sign proclaiming the altitude in meters and feet (1,507.5 and 4,946, respectively), a decrepit National Weather Service trailer, a porta-potty, and a view of nothing but scrub brush, arid buttes and the occasional volcanic cone. At nine in the morning on a typical sun-blessed August day, it's already hot enough to cause sunstroke, if not imminent heat exhaustion—although it is a dry heat, to put it mildly. The mountain gets less than 20 centimeters of rain a year, and only about a centimeter sticks around long enough to soak into the soil and percolate down through the mountain.

Desert wasteland: Canisters like this one, on exhibit at Yucca Mountain, would contain the nuclear waste scheduled to be shipped to the mountain starting in 2010.

It's this combination of aridness and desolation—Nye County, NV, the home of Yucca Mountain, has a population density of less than one person per square kilometer—and the fact that the locals have already put up with decades of nuclear-weapons testing that convinced the U.S. Department of Energy in the mid-1980s that Yucca Mountain might be an ideal location for storing in perpetuity the nation's accumulation of spent nuclear fuel. Since then, DOE scientists and contractors have dug an eight-kilometer-long, 7.6-meter-in-diameter tunnel down into the mountain, spent over $3 billion studying the local geology to make sure waste won't leak from the mountain, and worked their way, with the vigorous help of the U.S. Congress, into a political, financial and public-relations quagmire so seemingly hopeless that no amount of technological wizardry or political gamesmanship is likely to resolve it. "It's not clear what kind of political action will be necessary to get Congress to say, 'All right, we're right to go ahead with Yucca Mountain,'" says John Ahearne, a former director of the U.S. Nuclear Regulatory Commission. "But one thing you can certainly say is Yucca Mountain is not going to be going forward rapidly."

Digging deep: To study Yucca Mountain's suitability as a nuclear-waste repository, the DOE has dug an eight-kilometer-long tunnel 300 meters down into the mountain.

For the past quarter-century, the failure to dispose of the nation's accumulating nuclear waste has been the single most damaging public-acceptance problem for the nuclear industry and perhaps the primary reason that no new nuclear power plants are likely to be built for the foreseeable future, notwithstanding any additional power shortages of the kind that struck California last summer. At the moment, 103 nuclear plants are operating in the United States, generating about 20 percent of the nation's electricity and accumulating spent fuel at a rate of 2,000 metric tons each year. They have amassed over 40,000 metric tons so far—enough to cover a football field to a depth of nearly five meters—and it's all booked for burial in Yucca Mountain, should the project ever emerge from its morass.

OVERWHELMING OBSTACLES

Originally planned to open as a permanent nuclear-waste repository in 1998, Yucca Mountain is now scheduled for a 2010 opening, although few experts outside of the DOE think that date is remotely plausible. The problem, as a 2001 National Research Council report put it, is not technical but societal, which could be the mantra of nuclear-waste disposal. The project, said the council, has been haunted by a "clear lack of public confidence and support," and for good reason: "Difficulties in achieving public support have been seriously underestimated in the past, and opportunities to increase public involvement and to gain public trust have been missed." In other words, the disposal of high-level nuclear waste is a problem that, while technical in nature, cannot be understood out of the context of its own political history and the societal attitudes that have evolved as a response.

Two overwhelming obstacles confront the program. The first is that the proposed repository must keep radioactive spent nuclear fuel sequestered from the environment, or at least from the local inhabitants, for 10,000 years, long enough for the bulk of the radioactivity to die away. That 10,000 years happens to be roughly twice the span of recorded human history suggests the nature and scope of the challenge. Launched in 1957 with a National Academy of Sciences report insisting that "the hazard related to radioactive waste is so great that no element of doubt should be allowed to exist regarding safety," the project has had to come to terms with the fact that such absolute certainty, or anything close to it, is an impossibility. "You're not going to be able to prove, in any normal sense of the word, that you won't get harmful releases to the environment," says Ahearne. "You can have a certain level of confidence that you won't, but that will never be enough to prove it and convince the opponents."

Problem number two is that nuclear waste is accompanied by a stigma with few equals in modern times. Over the past two decades, researchers have done scores of studies on the societal perception of nuclear waste, and the results are singularly consistent: "People have a strong adverse emotional reaction" to

even hearing the words, says Paul Slovic, a University of Oregon psychologist who specializes in the study of risk perception.

The waste, unlike nuclear power itself, comes with absolutely no benefit and, as far as the public is concerned, unlimited downside. In a series of surveys sponsored by the Nevada Nuclear Waste Project Office in the late 1980s and early 1990s, Americans suggested that they would rather live near a chemical-waste landfill, oil refinery or pesticide plant than a nuclear-waste repository. Indeed, those surveyed said that, even if they were convinced that a repository was harmless, the stigma of living near one would reduce the desirability of their communities, lower housing prices, deter tourists and job seekers and create a detrimental environment in which to raise children. This stigma is so profound, according to Richard Stallings, a former Idaho congressman who held the unenviable position of U.S. nuclear-waste negotiator from 1993 to 1995, that when he was talking to governors about the possibility of locating a temporary nuclear-waste repository in their states, they held the meetings surreptitiously in local airports or in his office in Washington so that constituents wouldn't get wind of the discussions and vote the poor open-minded politicians out of office.

Because Energy Department experts are all too aware of this stigma, and perhaps because of a culture that emerged from the nuclear-weapons program, the agency has had a regrettable tendency over the years to work in secret and has not earned public confidence by doing so. The department's early attempts to site a repository without consulting the states involved or making any effort to engage local participation "managed to provoke," as one study by Slovic's nonprofit Decision Science Research Institute put it, "two-thirds of the states into banning site exploration within their borders." By 1992, a task force commissioned by the DOE itself reported that, "by any conceivable indicator, the Department rouses little trust and confidence from any sector of the public," and went on to say the lack of trust was justifiable and not "an irrational action nor…a manifestation of the 'not in my backyard' (NIMBY) syndrome."

All of this has left politicians in a near hopeless situation when it comes to even contemplating nuclear-waste repositories in their home states—permanent or temporary—even if the promised compensation from the federal government and the nuclear-power industry is considerable. On the few occasions when an isolated community has agreed to host a repository for the sake of jobs and other economic benefits, the relevant governor and state legislature have inevitably opposed the plans because their broader constituency was overwhelmingly against the idea. The latest example is in Utah, where in 1997 the Skull Valley Goshutes, a local Native American tribe, signed an agreement with a utility consortium to house a $3 billion private interim storage facility on tribal land some 100 kilometers southwest of Salt Lake City. The local county has also signed onto the agreement, and the federal government and the Nuclear Regulatory Commission, which would have to license it, seem favorably inclined, says Harvard University's Matthew Bunn, coauthor of a 2001 joint report by Harvard and the University of Tokyo on the interim storage of spent nuclear fuel.

Nonetheless, the state has been vociferously opposed; Governor Michael Leavitt has been quoted as saying that nuclear fuel would be shipped to the reservation only "over my dead body." Says Bunn, "At one point, the state government threatened to seize all the roads around the site, creating what the governor called a 'moat' that would prevent anybody from shipping into the site. But some of the roads turned out to be federal roads that the state couldn't seize, so that didn't work."

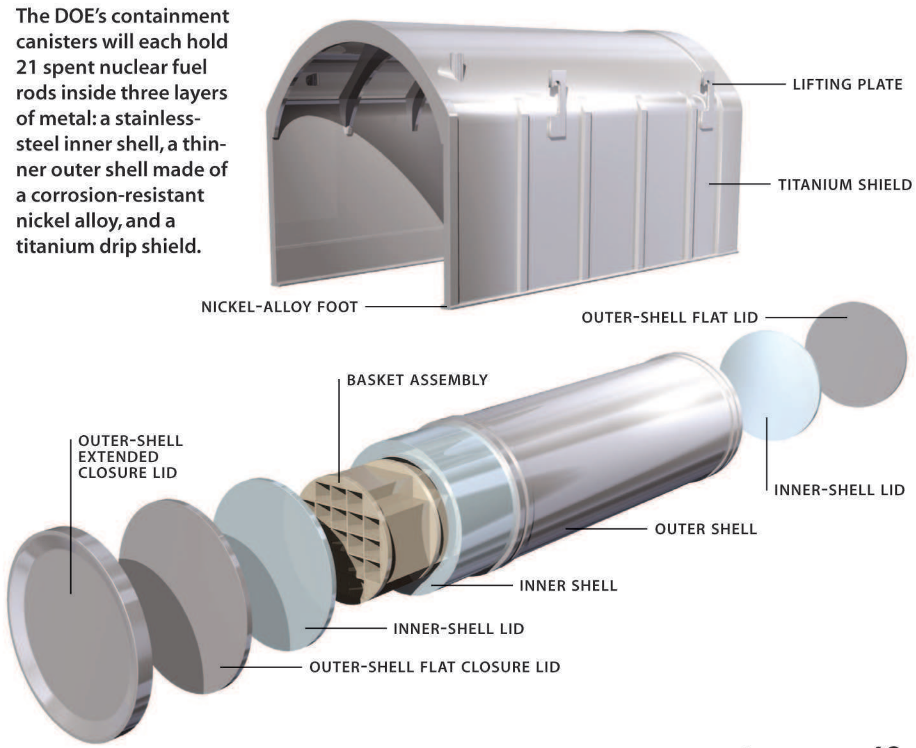
THE "SCREW NEVADA" BILL

In 1957, when the U.S. Atomic Energy Commission, the predecessor of today's DOE, asked the National Academy of Sciences what to do with the spent fuel that would someday emerge from the commercial nuclear-power industry, the academy put together a committee of experts that concluded the waste should be interred deep underground. The committee went on to say that such repositories were "technologically feasible," and indeed, sites should be identified, and "safe disposal means established," before the government authorized construction of any civilian nuclear reactors—advice the government did not follow.

As the commercial nuclear-power industry matured, the Atomic Energy Commission spent the next 25 years investigating prospective sites and getting nowhere, primarily because of political opposition from states with such sites. In 1970, for instance, after Oak Ridge National Laboratory researchers spent years studying candidate salt mines in Lyons, KS, the commission announced that the mines would house the nation's first nuclear-waste repository. Depending

Nuclear Containment

The DOE's containment canisters will each hold 21 spent nuclear fuel rods inside three layers of metal: a stainless-steel inner shell, a thinner outer shell made of a corrosion-resistant nickel alloy, and a titanium drip shield.



Nevada nix: State nuclear-waste official Robert Loux uses DOE and independent scientific assessments like those behind him to help Nevada block the Yucca Mountain project.

PHOTOGRAPH BY ANGELA WYANT

on your point of view, the plans were abandoned two years later either because "the State of Kansas adopted a resistant position," as one Oak Ridge history put it, or because the mines, as noted by geologists hired by the state, were riddled with mining industry boreholes that were likely to let water in and waste out.

Through the 1970s, pressure to deal with the spent-fuel problem grew with the environmental movement, which included strong opposition to nuclear power itself. By the early 1980s, the industry and the DOE were predicting power shortages and even blackouts as expensive and controversial storage pools inside nuclear plants filled with spent fuel, conjuring the threat of reactor shutdowns as nuclear utilities ran out of room to store their waste. This storage crisis never materialized, but it played well in the press and may have been the primary force behind congressional resolve, once and for all, to choose a site for a repository and build it.

Finally, after literally hundreds of attempts at legislation, the U.S. Congress passed the Nuclear Waste Policy Act of 1982, which directed the DOE to choose three sites to analyze in detail at a projected cost of $60 million per site and then pick the most suitable, so that a repository would be accepting spent fuel by 1998. Because most nuclear power plants are east of the Mississippi, and because the DOE was concentrating its initial efforts on western sites, the act also required that a second repository be planned for the east. And to safeguard states from being saddled with a repository against their interests, the act dictated that federal funding be given to states with candidate sites so that they could ride herd on the DOE analysis with their own monitoring and testing.

By December 1984, the Energy Department had narrowed the candidates for repositories to sites in Texas and Washington State and at Yucca Mountain—but the estimated $60 million characterization cost had already grown to more than a billion dollars per site, and the DOE was making slow if any progress. "It costs a lot of money to characterize three sites," says Robert Loux, director of the Nevada Nuclear Waste Project Office. "So Congress said, 'Let's pick one.'" With the Speaker of the House of Representatives, Jim Wright, from Texas and the House majority leader, Tom Foley, from Washington State, Nevada constituted the weakest link in the game of congressional politics.

The result was the Nuclear Waste Policy Act amendments of 1987, now often known as the "Screw Nevada" bill. The amendments exchanged the perception of fairness for expediency and designated Yucca Mountain the "winner" in the repository sweepstakes, forbidding the DOE from studying any other prospective sites. Stallings describes the amendments, which also canceled plans for a second repository in the east, this way: "Congress took the smallest and weakest state, politically, and then decided to shove the nuclear waste down its throat."

And the citizens and politicians of Nevada were not pleased. As the Harvard/University of Tokyo report put it, the inequity of the 1987 amendments assured that Nevada "would be resolutely opposed to the repository in perpetuity." In 1989, the Nevada state legislature passed a law declaring it "unlawful for any person or governmental entity to store high-level radioactive waste in Nevada." The U.S. Congress, led by Louisiana senator J. Bennet Johnston, a driving force behind the 1987 amendments, responded in 1990 by drastically cutting the funding for Nevada's Nuclear Waste Project Office and promising to restore it only if Nevada cooperated fully with the DOE.

SCIENTIFIC SLUGFEST

As for the idea that science somehow would determine the ideal resting place for nuclear waste, the 1987 amendments may have derailed that dream as well. By choosing Yucca Mountain as the only option for a nuclear-waste facility, Congress put the DOE in an untenable position. In effect, it sent the department out to prove that Yucca Mountain would work as a repository, rather than to do a dispassionate analysis of whether it could work or was the best possible site. The scientific assessment of the Yucca Mountain repository promptly devolved into a slugfest of competing experts. The Nevada experts, frequently with media help, publicized any findings that suggested that Yucca Mountain would leak nuclear waste through every pore, fault and fracture line, while the DOE experts inevitably responded that the problems were trivial and could be handled with simple engineering. While the DOE experts might indeed be right (and most unbiased technical experts believe they are, says Harvard's Bunn), their objectivity will always be in doubt.

The back-and-forth between state and DOE investigators has only intensified that doubt. The original concept behind deep underground repositories like Yucca Mountain, as Loux points out, was that the sites' geology and climate would enable them to contain the nuclear waste placed within them. The more geologists have learned about Yucca Mountain, however, the less viable that model has become. Loux cheerfully lists the litany of Yucca Mountain's potential failings, all of which the DOE acknowledges. The immediate region, for instance, has over 30 fault lines running through it—"an extraordinary number" for an area of some 250 square kilometers—one of which registered a magnitude 5.6 earthquake in 1992, causing significant damage to the DOE buildings at Yucca Mountain. There are also three or four relatively young volcanic structures within a few miles of Yucca. "If you're trying to find a good, stable geologic foundation for a repository," says Loux, "it's not available at Yucca Mountain." What's more, he adds, the DOE originally assumed that the arid environment and the fused volcanic rock of the mountain would keep water from percolating down into the repository, but geologists quickly discovered that the mountain is riddled with tiny fractures, and what water does get in moves relatively quickly, in geologic time, on down.

And so it goes. Energy Department experts say the earthquakes are irrelevant because the damage caused by the tremors is felt only at the surface of the earth, not hundreds of meters down where the repository would be—just as you don't feel an ocean wave passing over you when you're submerged underwater. As for the volcanoes, the chance of one emerging to do damage to a Yucca Mountain repository in the next 10,000 years is vanishingly small.

"Conceptually," says Bunn, "one has to draw back and think, wait a minute: if 10,000 years from now people are still drinking water from wells near Yucca… and there's no testing of that water for radioactive contaminants and there hasn't been a cure for cancer in the interim, that suggests something truly awful has happened to civilization in the meantime. Then we have to ask, is the best

Test tube: Almost three kilometers inside Yucca Mountain, DOE researchers study how nuclear waste might affect the stability of the planned storage facility.

thing we can do for those people spending lots of money on the repository rather than, say, preventing global warming?"

As the understanding of the Yucca Mountain geology has evolved, the DOE has turned to technology to provide the certainty necessary for long-term storage. In particular, the agency's engineers have vastly improved the canisters expected to contain the nuclear waste within the mountain. While the original plan was to let the geology of the mountain do the bulk of the containment work, says Jeff Williams, a nuclear-waste expert in the DOE's office of civilian radioactive-waste management, the new plan is to let the engineering do it. "The canister, holding 21 spent fuel assemblies, will be two inches thick of stainless steel," he says, "covered by half an inch of a very corrosion-resistant nickel-metal alloy, called Alloy 22. On top of that, for an extra layer of redundancy, we have what's called a drip shield made out of titanium."

So even if water gets into the repository, Williams explains, it would have to eat through the drip shield, then through the alloy layer, then through the stainless steel, and then it would have to dissolve the uranium itself, which is not particularly soluble. Finally, this radioactive water would still have to percolate down to the ground water—which at present is another 200 to 400 meters below the level of the repository—and then be carried another 30 kilometers to the wells of the nearest human settlements. While all this could conceivably happen, the DOE simulations suggest it would take considerably longer than the requisite 10,000 years and even in the worst-case scenarios—volcanic eruption, for instance—would be unlikely to release sufficient radiation to violate the standards set for the repository by the U.S. Environmental Protection Agency.

That's technology, however, and the salient issue here is societal. The intractable, if not perverse, nature of the conflict between the DOE and the state of Nevada is demonstrated by the simple fact that the Nevada experts do not dispute the federal agency's assessment of the robustness of the new waste packages. Rather, they simply point out that if the DOE felt compelled to make waste packages so stout, it must have done so because it also believes that Yucca Mountain itself is an unsatisfactory repository. And now that the DOE has created canisters that can safely contain waste for tens of thousands of years, says Loux, the agency has rendered the geology and climate of Yucca Mountain irrelevant. It could bury the waste under the bleachers at Fenway Park, and it would be equally safe. For the DOE, it's a no-win situation.

STARTING FROM SCRATCH

By year's end, the secretary of energy will have to decide whether to recommend to the president that the nation actually build a nuclear-waste repository at Yucca Mountain. While few experts can envision a scenario in which the DOE chooses not to press forward and begins looking at new sites instead, neither can they envision the repository being built on schedule, if at all. If nothing else, once the Democrats obtained a majority in the Senate last spring, when Vermont senator James Jeffords defected from the Republican Party, Senator Thomas Daschle, a South Dakota Democrat and the new majority leader, vowed that the Yucca Mountain Project was effectively dead. Meanwhile, Nevada has considerably more political clout than it did in the 1980s: the Senate majority whip, Harry Reid, is from Nevada and dead set against Yucca Mountain.

Nevada also has a backup plan ready should the Yucca Mountain project show signs of moving forward. It's what Loux calls the "transportation issue" and the environmental movement has dubbed "rolling Chernobyls." A Yucca Mountain repository would eventually be home to 70,000 metric tons of nuclear waste that would make its way to the mountain in some 56,000 truckloads. This works out to about six trucks a day for the next 30

Rock solid?: Branching off the main study area, the left-hand tunnel descends some 300 meters below Yucca Mountain, where DOE geologists study the rock structure near the proposed storage area.

years. So far, the safety record of nuclear shipments around the country has been "enviable," says the Harvard/University of Tokyo study, and no single shipment has ever released any known radioactive material. But once again, that's a technical point. Nevada, on the other hand, is prepared to play on the fears of every community that might someday see a truckload of nuclear waste rumbling down the local interstate in the interest of gaining support against Yucca Mountain from the 43 states along the shipping routes.

"The DOE wants to keep the argument over Yucca Mountain bottled up in Nevada and Washington, DC," says Loux. "But once people on these routes learn about what's in these shipments and when they'll take place, they'll become pretty agitated. The governor has already got a couple of million dollars from the Nevada legislature to carry out a national campaign. And casinos in Las Vegas have pledged another eight or ten million dollars to help advertise the transportation issue. They believe, correctly so, that it could end up being one of the issues that stops the project."

If there is an easy way out of the impasse, say experts, it isn't obvious. However, in the past year both the National Research Council and the Harvard/University of Tokyo collaboration advanced an idea that seems to be gathering support among experts in the nuclear-waste debate. The gist of it is to slow down, rethink and do it right. The current repository plans were motivated in the early 1980s by the specter of reactor shutdowns and blackouts as spent-fuel storage pools around the country filled to the brim. Since then, the industry has learned to store spent nuclear fuel on-site in dry-storage casks. These concrete or steel casks are easy to use, easy to license and, according to the Nuclear Regulatory Commission, will keep the spent fuel safe for a century. Indeed, says the DOE's Williams, everyone agrees that dry-cask storage, known technically as monitored surface storage, is an adequate temporary solution to the problem of spent fuel, at least from the safety and security points of view. "From a what's-the-right-thing-to-do perspective, it's another question," he says. "Should we leave this waste forever for our children's children's children to take care of, and have them continue to maintain these casks at 100 places around the country?"

Both the National Research Council report and the Harvard/Tokyo study suggest that dry storage be used for the near term while the government goes about siting a repository correctly. What constitutes "correctly" can be effectively defined as the opposite of what has been done so far. Among the report's key recommendations, for instance, are to "assure that choice is available," and that there be "greater openness, transparency and full public involvement in decision making, including real opportunities for the public to influence policy choice."

The National Research Council and others see this kind of open approach as the only way to get the public to trust both the government and nuclear-waste experts and to voluntarily accept repositories somewhere in the vicinity of its backyards. "You have to involve critical elements of the public in the decision-making process," says risk perception specialist Slovic, who has been dealing with the nuclear-waste issue for over a decade. "They have to be brought into the arena, given some status, listened to and respected. This approach is not a quick fix. It takes time and a sincere effort. It's not necessarily efficient, but on the other hand, our managing of nuclear waste up to this point has not been efficient. We've spent several decades floundering and spending billions of dollars and not getting anywhere. Without a new approach, people are just going to continue to fight it." TR

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Lab work: Roy Periana is searching for catalysts that will turn natural gas directly into liquid fuels.

BY DAVID VOSS

Hitting the Natural-Gas JACK-POT

The world's vast reserves of natural gas easily rival oil supplies—and could far surpass them. The key to unlocking this nearly limitless supply of energy could be finding the perfect catalyst.

PHOTOGRAPHS BY MISHA GRAVENOR

Compared to oil, natural gas is so abundant it's staggering. Proven petroleum reserves are good for another one trillion barrels or so. At today's rate of consumption, they will last about 40 years. Add in oil reserves thought to exist but still undiscovered, and the timeline stretches out some 160 years.

Known reserves of natural gas, which is composed mainly of the simple hydrocarbon methane, will last for about 50 years at today's consumption rate. Estimates of likely but as yet undiscovered gas resources extend that projection to about 200 years. But when the natural gas thought to lie buried deep under the ocean in methane hydrates is added in, the potential is mind-boggling. Hydrates, ice crystals that trap methane molecules, form below a depth of 300 meters as a result of methane-producing bacteria. Very little is known about how much gas is bottled up in these crystals or how to get it out, but best guesses are that the reserves could, even with natural-gas consumption rates doubling over the next several decades, last tens of thousands of years.

However you do the arithmetic, there's a lot of natural gas out there. Adding to its attractiveness as the fuel of the future is that methane is far cleaner burning than oil. But there's a big problem: natural gas is volatile and expensive to transport. One of the beauties of oil is that you can pour it down pipes, load it onto tankers or barges and safely ship it around the world. Natural gas, by contrast, is most often shipped as a liquid, which must be maintained at a temperature of -130 °C or at tens of atmospheres of pressure. It can also be transported as a gas in pipelines, but because the gas must be kept compressed, that is an expensive proposition: one estimate is that a pipeline to get gas out of Alaska and into the Lower 48 would cost around $15 to $20 billion to build.

Throw in the fact that many large reserves are in remote locations like Alaska's North Slope or Siberia, and the result is that much of the world's natural gas is now commercially worthless. "Of the [natural gas] that everyone agrees is there, over half has absolutely no market [value]," says Mark Agee, president of Syntroleum, a Tulsa, OK, energy firm. "None whatsoever. It's in places like the northwest shelf of Australia, Papua New Guinea, the west coast of Africa, the North Slope of Alaska. Really remote places with no ready market close by."

For a chemical engineer, the solution to this quandary, in theory at least, is relatively simple. If you could chemically transform this dangerous gas into a liquid hydrocarbon, like synthetic oil or even gasoline, it could be transported easily and cheaply at room temperature and normal pressure. These synthetic fuels could flow right into existing oil pipelines or be put aboard tanker ships bound for market. After further refinement, they could even be distributed through the existing network of service stations. As an added bargain, since the starting material is virtually-zero-sulfur natural gas, the resulting fuels would also be free of the sulfur and aromatic pollutants that taint other petroleum products. You would, in other words, have a readily available source of fuel that is potentially far cheaper and cleaner than oil.

Some of the world's largest oil companies are now investing billions of dollars to build refineries that use "gas-to-liquid" technology to convert methane into ultraclean diesel and gasoline fuels. Using high-pressure, high-temperature refinery processes, these new plants, which are being constructed in places such as Bintulu, Malaysia, will turn natural gas into liquid products that are easily shipped to market and quite likely cost-competitive with petroleum products.

But some researchers believe they have a far better idea. The processes used at the new plants are based on chemistry that dates back to the early 1920s and are costly and inefficient. A small group of chemists and chemical engineers is working to discover catalysts—materials that speed up chemical reactions but are not themselves consumed in the process—for directly converting natural gas into liquid fuels at low temperatures and pressures. If these catalysts work—and that is still a giant *if*—they will make possible cheap, simple refinery processes that could unleash the vast untapped reserves of natural gas. Indeed, they would force experts to redo their calculations of the world's energy supplies. Suddenly, the untapped methane resources in Siberia and northern Canada could be just as important to the world as the vast oil fields of Saudi Arabia.

BLACK PAST

The idea of making liquid synthetic fuels is not new. In 1923, two German coal researchers, Franz Fischer and Hans Tropsch, discovered a way to turn the copious coal reserves of the Ruhr Valley into synthetic oil. Fischer and Tropsch knew that if they heated up a pile of coal, they would produce a mixture of carbon monoxide and hydrogen. The scientists found that by passing this gas over metal catalysts they could make synthetic fuel. During World War II, the German government used the Fischer-Tropsch process to produce around 600,000 barrels per year of military fuel from the country's plentiful coal deposits.

After the war, Allied intelligence agencies tore the German plants apart to figure out how they worked, and a small Fischer-Tropsch plant was operated in Brownsville, TX, from 1948 to 1953. In the 1950s, the South African government found itself, like the Nazi regime, with little or no access to petroleum; it turned to the Fischer-Tropsch process and built several plants to convert coal from the country's extensive deposits into synthetic fuels.

And there the technology might have stayed, confined for the most part to nations starving for oil, except for today's growing temptation to tap into the vast reserves of remote, cheap natural gas. Methane, like coal, can be used to produce a mixture of carbon monoxide and hydrogen; except for the starting material, the fuel synthesis process works exactly the same as with coal. Exxon Mobil, Shell and South Africa's Sasol are all involved in big projects to convert natural gas into liquid. All told, the major oil companies plan to spend nearly $10 billion on gas-to-liquid capacity in future plants.

Pipe dreams: Syntroleum's president Mark Agee is betting the company's natural-gas process will be cost-competitive with oil.

One of the smaller, more aggressive players is Tulsa's Syntroleum. Like the big oil concerns, Syntroleum is banking on Fischer-Tropsch conversion to turn stranded natural gas into easily transported ultraclean liquid hydrocarbons. Thanks to improved catalysts and reactor design, the company says, liquid hydrocarbons made from methane are now extremely competitive with oil in the marketplace. "The synthetic fuels we can make are 100 percent compatible with conventional products," says Syntroleum president Mark Agee. "With natural gas, the feedstock cost [in oil-equivalent barrels] is anywhere from zero to $10 a barrel, compared with petroleum at $20. We've had gas offered to us on the west coast of Africa at a nickel per thousand cubic feet, or 50 cents a barrel."

PERFECT CATALYST

But the Fischer-Tropsch process is inherently inefficient and expensive—and from a chemist's viewpoint, inherently clumsy. The process requires temperatures of around 800 to 900 °C, and those are achieved by burning part of the gas that's being converted. The technology is also relatively nonselective, producing a large range of hydrocarbon molecules, some of which are useless. "Fundamentally, what's wrong is that it's 1940s technology," says Roy Periana, a chemist at the University of Southern California. "It uses brute force and high temperatures to achieve the conversions."

Give any organic chemist a pencil and pad of paper, and he or she could quickly draw out a simple, more elegant route to liquid hydrocarbons. Natural gas is largely methane; transforming it into methanol, an easily transportable liquid, is simply a matter of adding an oxygen atom to the methane molecule. There are, however, a couple of big problems in turning this direct-synthesis theory into chemical reality. The catalyst needs to break the tight carbon-hydrogen bonds in methane to allow the oxygen to react. And—here is where it gets really tricky—the reaction needs to add a single oxygen atom to each methane molecule; allow it to continue and add an additional oxygen atom, and you create worthless carbon dioxide.

The trick can be pulled off in the lab, but existing catalysts are not efficient enough to produce the yields required to compete with oil. Periana, for one, has been chasing the perfect catalyst for more than a decade. In the mid-1990s, Periana worked at a small California company called Catalytica, where he led a team working on new catalysts for this direct conversion. "At Catalytica, we discovered two systems," he says. "One was a mercury catalyst that gave 40 percent yield in one step at 180 degrees. The other was a platinum system that gave 70 percent yield at 220 degrees. At that point, people began to say that maybe this was really possible." But these promising starts ran smack up against some immutable facts of basic chemistry. While the direct conversion of methane was impressive from a chemistry point of view, it still wasn't commercially viable. "If you're going to replace a commodity process like this," says Periana, "you really have to have a revolutionary process. Marginal improvements are not going to do it."


Liquid gold: Synthetic diesel and other fuels made by Syntroleum could take advantage of vast, cheap reserves of natural gas.

Despite the chemistry roadblocks, Periana remains optimistic. "We have some leads, and we're coupling that with knowledge of how previous systems have worked. And right now, it's fair to say that this is a race. The fundamentals are laid down, and it's a matter of who will get there first," he says. "The question on everyone's mind now is who will find the right catalyst and when, and what will it be. It's not even a question of 'if.'"

NATURE'S PUZZLE

Even major oil companies investing in converting methane into liquid fuels through indirect approaches are funding research on direct conversion. Last year, BP awarded $1 million per year for 10 years each to the University of California, Berkeley, and Caltech for methane conversion research —with part of the grant earmarked for direct conversion. The catalyst search, says Alex Bell, a chemical engineer at Berkeley, "is a combination of art and science. I cannot sit down right now and say there is an algorithm for finding a catalyst for a given reaction. You build off past knowledge of what works and try to improve it with a knowledge of fundamental chemistry. Much of it is trying to establish patterns, and strategic thinking about the chemical principles that take methane to targeted products."

And no one expects a breakthrough tomorrow. Enrique Iglesia, another Berkeley chemical engineer involved in the BP program, has been working on methane conversion for almost 20 years. "Direct methane conversion is something we dream about, but nature gets in the way," he says. "Methane has one of the strongest bonds we know, and its reaction products usually have weaker bonds. It's tough to stop at the desired products, so this is tough chemistry."

Few might suspect the solution to the world's energy problems will come out of the esoteric field of catalysis science. But with the vast, untapped reserves of natural gas out there fueling the imaginations of chemists, the search for the perfect catalyst is continuing. Tough chemistry, but if it succeeds, it will change the world's energy calculations. TR

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ELECTRICITY GOES TO MARKET

Spotting trouble: Thomas Overbye says the power grid was never designed for today's new business practices.

DEREGULATION WAS SUPPOSED TO CREATE A FREE MARKET FOR ELECTRICITY THAT WOULD DRIVE PRICES DOWN. BUT IT HASN'T EXACTLY WORKED OUT THAT WAY—JUST ASK ANYONE IN CALIFORNIA. THE AGING POWER TRANSMISSION INFRASTRUCTURE, IT TURNS OUT, IS SIMPLY TOO RIGID AND INEFFICIENT TO MEET THE NEW DEMANDS.

BY ROBERT POOL

PHOTOGRAPH BY STEPHEN KENNEDY

Economists aren't generally known for consensus of opinion, but there's one point on which almost all of them agree: regulated markets are less efficient and end up costing consumers more than unregulated markets. It is this conviction that has driven the deregulation of the electric utility industry over the past decade. In a free electricity marketplace, the theory goes, the forces of supply and demand would drive the industry to become more efficient and reliable. Electricity prices would drop, supplies would increase and companies would make rational investment decisions based on expected returns. Because one unit of power is indistinguishable from any other, electricity would ultimately become a commodity, bought and sold on the basis of price with no concern over whether it was produced a few kilometers away or halfway across the country.

Time has shown, however, that the road to commoditization will not be without its bumps. As the California energy crisis of 2000 has demonstrated, partial deregulation—in this case, letting wholesale electricity prices float while keeping the retail price capped—can make matters worse. And as long as public opposition to new generating plants remains high, the supply of electric power will have difficulty keeping up with demand, no matter how enlightened the deregulatory policies.

But as those who study the electric industry point out, there's an even more fundamental obstacle to realizing the promise of deregulation: the technology itself. Nearly everything in the current power system—from the generating plants and the transmission grid that distributes electricity throughout the country to the devices that run on that power and the meters that keep track of power usage—is designed for use in a centralized system of regulated, monopolistic utilities that produce power at a few locations and ship it out to local customers at a fixed price. While the regulatory policies have begun to change, the technology, for the most part, has not kept up.

Take the power grid, for example. Utilities began building this network of transmission lines over 100 years ago to bring power from their generating plants straight to their customers. In the early 20th century, they began to interconnect their transmission systems so that a utility that needed extra power might buy it from a nearby firm; but these uses remained a small part of the grid's traffic. Thomas Edison himself—who came up with the grid's original hub-and-spoke design—would likely have no difficulty recognizing today's transmission system. But while Edison's design has sufficed for a century, it doesn't offer the flexibility required to turn electricity into a commodity.

"People are trying to operate the grid in a way it wasn't designed for," says Thomas Overbye, a power systems expert at the University of Illinois at Urbana-Champaign. "When you try to treat electricity as a commodity, you change the whole flow pattern." A customer in Pennsylvania, for example, might now contract for power from a supplier in Illinois, through an electricity reseller who would pay for transmission rights on the lines between the two places. As a result, the electricity may be traveling a thousand kilometers instead of a few hundred, and because electrons follow the path of least resistance, the current will distribute itself over a variety of routes between source and destination, not just the single transmission path that has been paid for. As more and more customers—mainly large industrial concerns and utilities themselves—have gone further afield to find the least expensive power, traffic on transmission lines has increased to the point that a growing number of them are bumping up against their maximum capacity. It will only get worse in the future, as competition and choices increase, prompting more users to look beyond local utilities.

Similarly, a number of utilities have voluntary programs that give residential consumers a price break in exchange for installing energy-saving controls on their air-conditioning systems and water heaters. At peak hours, the utility sends a signal wirelessly or via the power lines that changes the thermostat setting on air conditioners or shuts down water heaters for a while.

Both the commercial and the residential programs are effective in their limited goals—helping utilities pull back from the brink when they near capacity. But neither explicitly involves the consumer in the decision to cut back on demand, says Steve Hauser, an energy systems expert at Pacific Northwest National Laboratory in Richland, WA. And if electricity is ever to become a true commodity whose price is set by the interplay of supply and demand, the demand will need to be determined by millions of individual decisions made around the grid.

POWER INDUSTRY EXPERTS AGREE THAT UTILITIES WILL EVENTUALLY NEED TO MOVE TO "REAL-TIME PRICING," CHARGING MORE FOR ELECTRICITY AT PEAK TIMES AND LESS DURING PERIODS OF LOW DEMAND TO ENCOURAGE CUSTOMERS TO MOVE THEIR USE TO OFF-PEAK HOURS.

Help could be on the way. A new generation of technologies, some already in existence and some under development, could allow the power system to operate with unprecedented flexibility, efficiency and stability. Consumers could control the timing of their electricity purchases, in order to get the best prices. Homeowners and companies could operate their own generators, selling excess power back to the grid and helping to drive prices down further *(see "Power to the People,"* TR *May 2001)*. Electricity would finally become a true commodity, freely traded in an open market. One caveat: many of the systems that would enable such practices are still hypothetical, and realizing them could require a fundamental rethinking of how the grid is owned and operated.

GRID FRIENDLY

One way consumers might soon get the best prices for power—while at the same time reducing the strain on the grid—is by strategically timing when they buy electricity. Some large companies have been doing this in a rather crude way for years. A utility might offer them cheaper rates if they will agree to having their power turned off during times of peak demand. A company that can shut down operations for a few hours a few times a year can get a big break on its electric bill and can help utilities avoid overloading the grid.

To that end, Hauser's team is developing dishwashers, refrigerators, air conditioners and other appliances that turn themselves off for brief periods of time when they sense it will help the grid. The "grid-friendly" appliances contain a device that a user can program so that shutoffs can be overridden at times when an appliance's performance is critical. In times when the user's needs are more flexible, however, the device can monitor the quality of the electricity flowing from the socket, detecting changes that indicate that the region of the grid is in danger of a blackout. The devices work because disturbances to the grid, like spikes in demand that outpace supply, can make the voltage level and the frequency of the current's alternation deviate from their normal values. "If the frequency or the voltage started to shift, the appliance would drop off line for some period of time to allow the grid to stabilize," says Hauser. Customers, he suggests, could get a rebate or a credit each time an appliance tripped off line. Of course, the grid won't be saved by one or two dishwashers shutting down in a crisis, but Hauser envisions a time—perhaps as

Responsible refrigeration: Steve Hauser develops appliances that can detect when peak energy demand threatens the grid's stability and shut themselves off.

PHOTOGRAPH BY ROBBIE McCLARAN

Studying a solution: Marija Ilic thinks a whole new system for buying and selling capacity on power transmission lines is needed to promote innovation.

PHOTOGRAPH BY FURNALD/GRAY

soon as three to five years from now—when a significant percentage of appliances sold are grid friendly.

One advantage of Hauser's technique is that it does not depend upon providing special information to the appliances—all they need to know can be found in the current from the outlet. But ultimately, Hauser says, "we would like price signals to be sent down the line and have appliances respond to the price." There is widespread agreement among power industry experts that utilities will eventually need to move to "real-time pricing," charging more for electricity at peak times and less during periods of low demand to encourage their customers to move some of their use from peak to off-peak hours. Indeed, Washington State's Puget Sound Energy is already charging homeowners different rates at different times—most on weekday mornings and evenings, less during the day, and least at night and on weekends. The utility hopes its customers will respond by, say, waiting until after 9 p.m. to run the dishwasher or washing machine.

But ideally, says Karl Stahlkopf, vice president of power delivery at the Palo Alto, CA-based Electric Power Research Institute, utilities would be able to vary pricing hourly or even minute by minute, sending real-time prices to smart appliances that can modify their activities automatically. Air-conditioning systems, for instance, might crank their thermostats up a couple of degrees when energy prices peak. Eventually, appliances might even send information back to the grid about how much electricity they expect to need in coming hours and how much they would be willing to pay for it.

Just how appliances would communicate with the grid is anybody's guess, says Hauser: "It's like trying to predict in 1985 where the Internet was going." Researchers have suggested using phone lines, the Internet and satellite communications, among others. Some are even looking into transmitting the information along with the electricity, so an appliance would not need a separate hookup to keep abreast of fluctuating prices. But regardless of how the technical problem is solved, it's clear that real-time pricing and communicative appliances could go a long way to solving both consumers' and utilities' woes.

SMALL POWER PRODUCERS SCATTERED AROUND THE GRID COULD HELP KEEP ELECTRICITY CHEAP AND PLENTIFUL—AND COULD ENCOURAGE ALTERNATIVE POWER GENERATION TECHNOLOGIES. BUT FOR NOW, AT LEAST, THIS SCENARIO IS CAUSING SOME TECHNOLOGICAL HEADACHES.

HEALING POWER

Turning electricity into a commodity, however, requires changes not only to the way power is consumed, but also to the way it's produced and distributed. With deregulation, a growing number of small power producers have begun sending electricity into the grid, and according to predictions from the U.S. Department of Energy, that number will skyrocket in coming years *(see "Changing Capacity," p. 80)*. Thus an increasing percentage of the total supply of electricity is expected to be provided by small, independent plants, many of them using solar cells, windmills or other unconventional means to generate power. Similarly, an increasing number of large power users—factories, office buildings and others—and even some homeowners are expected to operate their own generators and sell their excess power to their local utilities. Eventually, instead of a few large plants feeding electricity into transmission systems at a few points, power producers will be scattered around the grid, most of them small and many of them contributing power only when the price for electricity goes above a certain level or when they have excess capacity.

"Distributed generation," as this scenario is often called, could help keep electricity cheap and plentiful—and could encourage alternative power generation technologies. But for now, at least, it's causing some technological headaches. For one thing, each new generating unit must be tied into the grid in such a way that the 60-hertz oscillation of its electrical output is synchronized with the oscillation of the entire network, says Jeff Dagle, an electrical engineer at Pacific Northwest. "A generator in Florida is in lockstep with a generator in Illinois," he says. But there is no standardized way to establish such connections, making it difficult and expensive for nontraditional energy suppliers to hook up to the grid, says T. J. Glauthier, a former deputy secretary at the DOE who heads the Palo Alto, CA-based Electricity Innovation Institute. This in turn discourages new generators and drives up the cost of the electricity they supply, Glauthier says.

A number of startup companies are now working on affordable, standardized devices to keep small power generators in sync with the grid, and to allow them to communicate with consumers about price, availability and demand. Once such devices become available, costs should drop, and factories with backup generators or homeowners with solar cells on the roof may be able to compete with the utilities, at least on peak-load pricing.

Unfortunately, making it easy for more power suppliers to hook up to the grid could wind up threatening its stability. Today, the network's proper functioning is the responsibility of a number of systems operators, each in charge of a large, contiguous section. The systems operator monitors the grid and issues directions for the management of the generating plants and transmission equipment. The operator's most important function is to match electricity consumption with production, bringing new generating capacity on line as demand increases and taking it off line as demand falls. But as more power suppliers set up shop around the grid, the system becomes far more complex, says Steve Gehl, a director of strategic technology at the Electric Power Research Institute. This makes it much harder for central operators to know how the system is behaving and to direct it effectively.

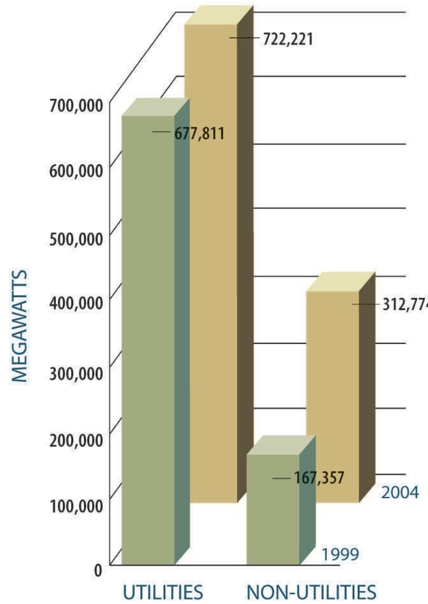
The best solution, researchers from the Electric Power Research Institute suggest, may be the creation of a "self-healing grid"—a system that constantly monitors itself to spot potential problems and then correct them before they lead to power outages or other disruptions. Here's how it would work: An array of sensors would detect everything from the voltage and current at junctions and substations, to the temperature of the air and the transmission lines, to the wind speed (a major factor in how efficiently the air cools the lines). Satellites would collect the data and forward them to a central location, where they would feed into a computer model that simulated the grid's behavior

over the coming minutes. With high-speed computers it should be possible to see problems arise in the simulations before they happen, and prevent them.

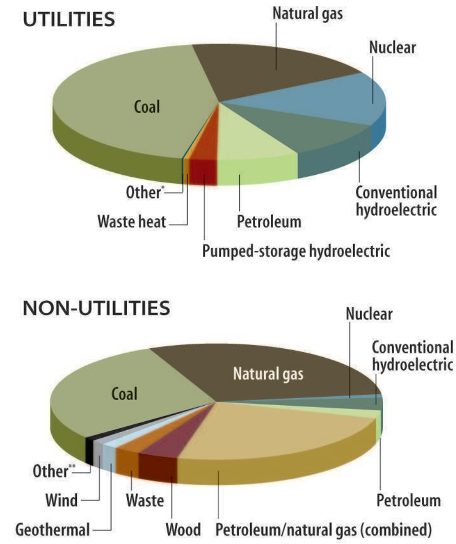
Take the case of a hot summer day, when consumers switch on their air conditioners and send demand skyrocketing. The sensors would be able to show if the transmission lines were beginning to heat up in certain spots. Before the wires could overheat enough to sag into trees, the central computers would use large electronic switches—giant transistors, in essence—to automatically reroute power as necessary, maybe even isolating a section of the grid to prevent it from taking the rest of the network down with it *(see "A Smarter Power Grid,"* TR *July/August 2001)*.

The challenges to making this scenario a reality are less technical than economic and political. Indeed, Gehl says, many of the technologies needed for such a self-healing grid already exist. But, he adds, there has not been enough attention to how the technologies would be hooked together in a system. Perhaps more important, nobody has been willing to make the investments that advanced, automated control of the electricity infrastructure will demand. The problem, Gehl says, is that "it's just not clear that people who invest in this development would be rewarded."

Changing Capacity



Independent production: From 1999 (the most recent data available) to 2004, utilities' total electricity-generating capacity is projected to grow only slightly, while that of non-utility producers will almost double.



*Includes wood, waste, geothermal, multifuel, wind and solar.
**Includes butane, propane and other gas, solar, batteries, chemicals, hydrogen, sulfur, purchased steam and pitch.

Unconventional means: Both utilities and non-utilities get much of their generating capacity from fossil fuels; non-utilities use proportionally more wood, waste, geothermal and other unconventional sources.

SOURCE: U.S. ENERGY INFORMATION ADMINISTRATION

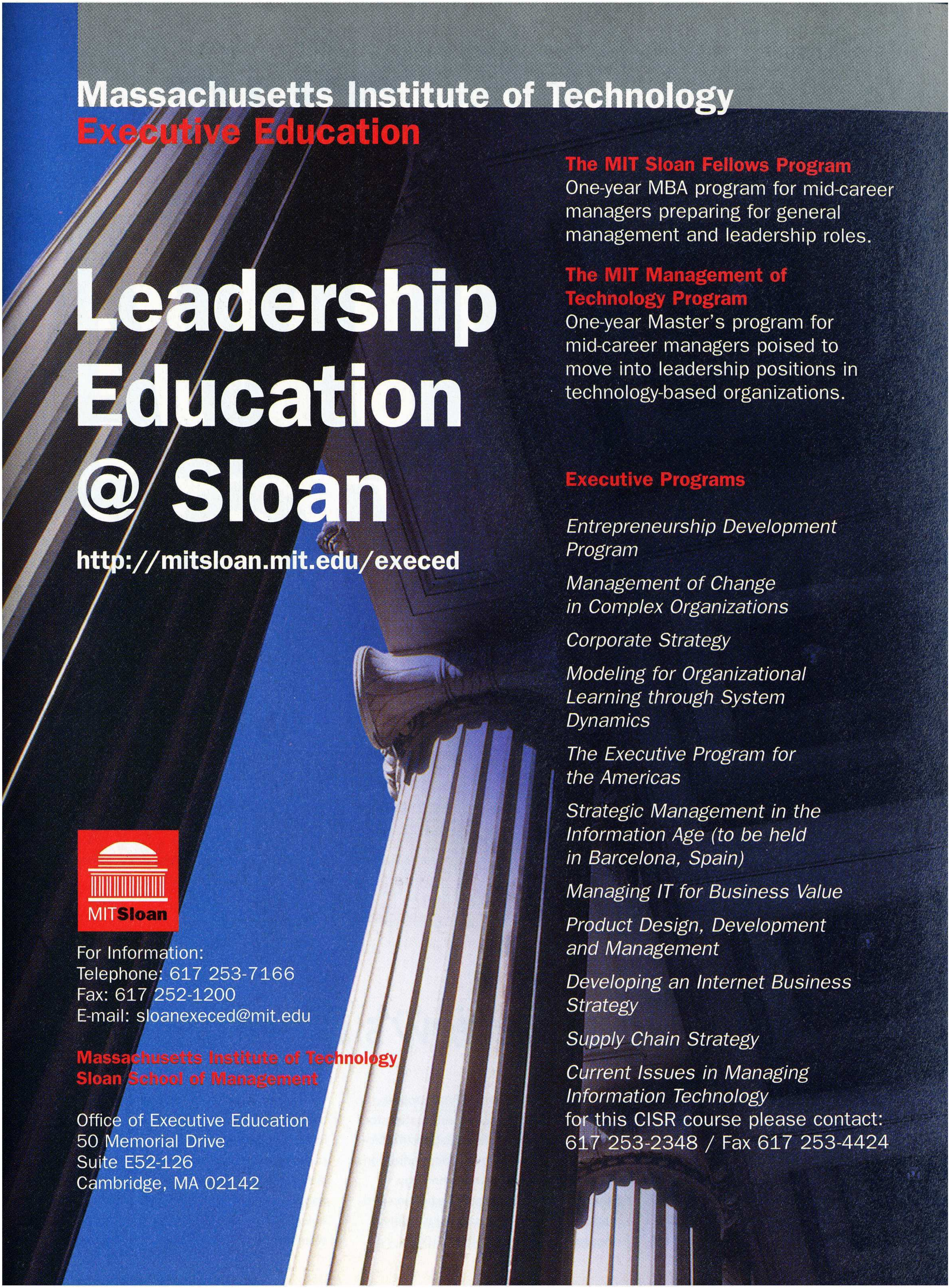
TRANSMISSION TRANSACTIONS

As the grid is now set up, explains Marija Ilic, a power systems engineer in MIT's Department of Electrical Engineering and Computer Science, there are few economic incentives to invest in improving it. In some parts of the country, the local electric utilities own sections of the grid, while in other regions parcels of the grid are owned by private transmission companies. But in either case, Ilic says, tight regulation stifles innovation. The owners of the grid are guaranteed a certain rate of return on their investment, and decisions about building new transmission lines are typically made by systems operators (federal or state governmental entities, depending on the region), based on studies about which parts of the grid are most vulnerable to overload. The operation of the grid is, in other words, the regulatory system at its worst. There is no way to reward entrepreneurs who take chances and provide new or better services.

Ilic suggests a dramatically different way of doing business. "We need an effective transmission market," she says, a place where transmission capacity itself can be bought and sold—and where profits flow to those companies that do the best job of meeting the transmission needs of others. The best hope of developing an efficient grid, Ilic says, lies in creating deregulated, for-profit transmission firms. She suggests having utilities divest themselves of their transmission systems—a step already taken in several parts of the country—and letting independent transmission companies compete for business. In general, anyone who wishes to get electricity from one part of the country to another has a choice of multiple paths owned by different companies; competition among those firms would lead to prices that reflect the real value of transmission to customers. The transmission companies, in turn, would have a good incentive to invest in technologies that could improve the stability and efficiency of the grid—as long as that was what their customers wanted.

Beyond the sorts of decisions that are best made by a free market, the University of Illinois at Urbana-Champaign's Overbye says, there are other, social and political, choices that can be made only by the broader society. A natural trade-off exists, for instance, between generation and transmission. To feed the growing appetite of southern California, producers could build generating plants nearby and put little additional strain on the grid, or they could build the plants far away and construct extra transmission lines. Should the denizens of Los Angeles put up with emissions from new coal-fired power plants, or should the inhabitants of Nevada put up with extra transmission lines carrying power across their state? To handle added demand for transmission, one can spend a great deal of money to upgrade the grid, adding expensive electronic switches and other specialty equipment, or else get more capacity for less money by building new lines—but at the cost of battling the not-in-my-backyard syndrome wherever the lines are planned to run.

"The key issue," Overbye says, "is we have to decide what we as a society want from our transmission grid. Then we can provide incentives to do that." Unfortunately, there has so far been precious little discussion about such fundamental issues. So while there may be agreement on the need for deregulation, and though the technology necessary to reap its benefits could be available soon, there is little consensus on just how we should put that technology to use. TR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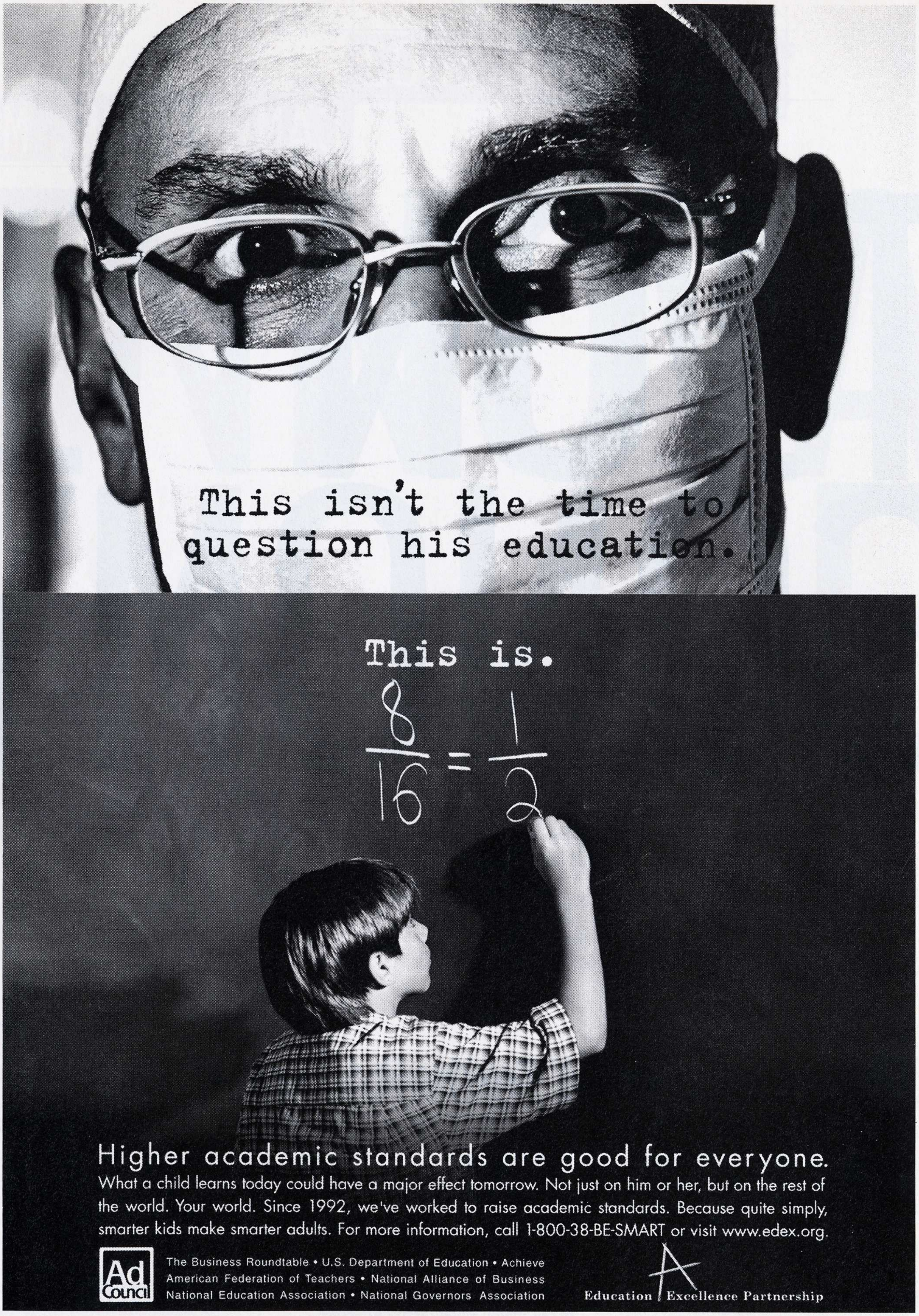
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PROTECTING PEOPLE ABOVE PATENTS

Let's say a government is at war. Imagine further that a powerful company holds a patent on technology vital to the government's ability to fight that war or protect its citizens. Wouldn't you assume that the government would place national protection far above patent protection?

Of course you would.

And this is indeed what happened, for instance, in 1917, when the U.S. government overrode the broad airplane patent held by the Wright brothers' powerful company as the nation prepared to enter World War I. I'll come back to this shortly, but first let's fast-forward to the troubled present. The contrast couldn't be more striking.

Early on in the anthrax scare last October—a month into the proclaimed war on terrorism—it almost seemed the Bush administration cared more about upholding Bayer's patent on the antibiotic Cipro (ciprofloxacin) than it did about safeguarding the public against bioterrorism.

With anthrax spores wreaking havoc from Florida to New York, shuttering offices in the nation's capital, administration officials announced that although the government wanted more Cipro to combat anthrax, it is illegal to break a patent. Questioned on CNN about New York senator Charles Schumer's prudent suggestion that Uncle Sam stockpile generic forms of the antibiotic from other manufacturers approved by the U.S. Food and Drug Administration to provide them, U.S. secretary of health and human services Tommy Thompson whined, "It does not look like we have the legal authority to do so."

Leaving aside the public health considerations, Thompson's claim about the government's lack of legal authority is utter nonsense. As many intellectual-property experts have since pointed out, the government would be on firm legal ground in overriding a company's patent by mandating licensing in such a situation if it chose to. Patents, after all, are government-granted monopolies; in times of war or crisis, the government has broad powers, especially in national security matters.

In this regard, Secretary Thompson would do well to consider the government's actions in World War I. Back then, the airplane was a relatively new technology. Armed with heavy Wall Street backing from Cornelius Vanderbilt and others, the Wright brothers' company—then called Wright-Martin Aircraft (precursor to today's Lockheed Martin)—held a virtual monopoly on the U.S. market. Recognizing that the Wrights' patent was thwarting the nascent domestic aviation industry and threatening the nation's ability to produce airplanes for the war, the federal government took bold action. At the urging of a young assistant secretary of the navy named Franklin D. Roosevelt, the feds mandated that the Wrights license their closely held airplane patent.

Among the results of this intervention was the Curtiss JN-4D, or "Jenny"—one of the most successful military aircraft of its day—manufactured by Curtiss Aeroplane. By the end of World War I, more than 6,000 Jennies had been built, and the vast majority of the approximately 9,000 American wartime-trained pilots learned to fly in these airplanes. Overriding the stranglehold of a broad patent in this case was the right thing for the government to do—both for the war effort and for the aviation industry.

This history lesson seems particularly pertinent in light of Secretary Thompson's claim of helplessness before the almighty drug patent.

Let me say that Bayer deserves criticism as well, despite ultimately agreeing to lower Cipro's price and despite its self-serving pledge to ramp up production to meet demand. This company sold $1 billion worth of Cipro in the United States last year and has two more years before its U.S. patent runs out—so it naturally sees control of the drug as vital to its bottom line. In this case, however, Bayer should have done the right thing and

A look at the Wright brothers case in World War I shows that in times of national crisis, the federal government is justified in overriding existing patents in order to safeguard the public.

offered competitors some kind of limited license to manufacture the drug as long as a credible, proven threat remains afoot. Should, heaven forbid, a large-scale anthrax attack take place, the nation might need enough antibiotics to treat the entire population for an indefinite period— far beyond the 100 million tablets Bayer has pledged to manufacture. In that dire event, Bayer executives would certainly regret their self-interested insistence on being the only U.S. supplier.

But Bayer is a drug company. Distasteful or not when lives are potentially at stake, its managers must worry about profits. The same cannot be said, however, for government officials entrusted by citizens to protect public health.

We have not likely seen the end of even the current spate of bioterrorism. True, Secretary Thompson has encouraged the use of other antibiotics for anthrax treatment, removing further pressure from Bayer. But as important as the Bush administration clearly believes patents to be, it is wrong to treat these government-granted monopolies as sacrosanct.

Letting the intellectual-property community know that extraordinary times can call for extraordinary measures does little to damage the patent system. On the contrary, by inserting a sense of priority that places people above patents, the U.S. government strengthens the system in the long run. TR

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COURTESY OF WAVEGEN; ILLUSTRATION SOURCE: WAVE ENERGY RESEARCH TEAM, UNIVERSITY OF LIMERICK

By Tracy Staedter | Illustration by John MacNeill

WAVE POWER

How the rolling sea generates electricity

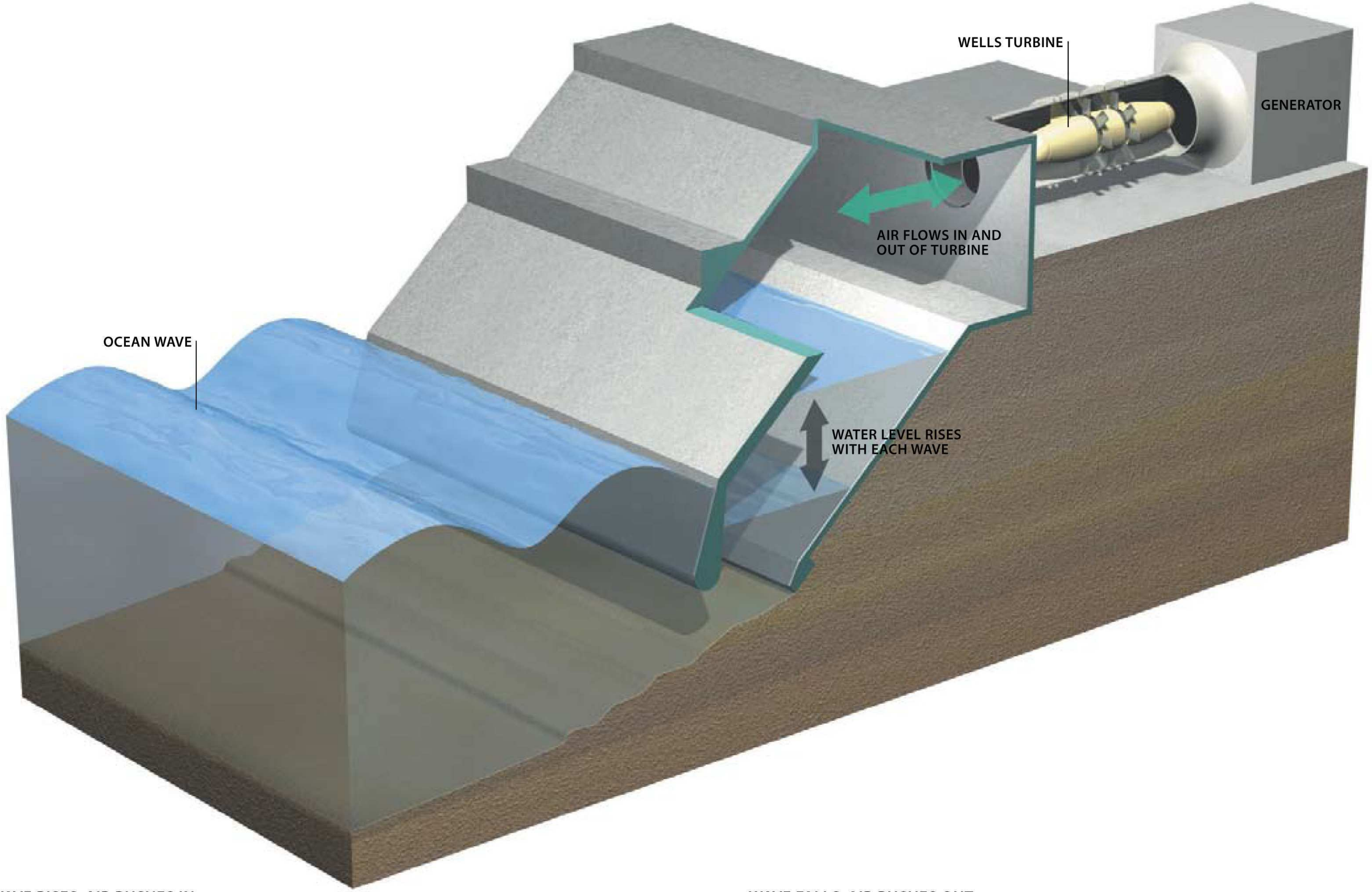
For decades, scientists have been trying to tap wave power as a source of renewable energy. According to the World Energy Council—an international consortium promoting sustainable energy—ocean waves could supply twice as much electricity as the world now consumes. But wave action is so dispersed, it's difficult to harvest this power economically.

Wavegen, an Inverness, Scotland-based company, is trying. In November 2000 it installed the world's first commercial system to generate electricity directly from the surf. Located near the town of Portnahaven on the Scottish island of Islay, Wavegen's system—called the Land-Installed Marine-Powered Energy Transformer, or Limpet—can generate 500 kilowatts of power reliably, enough for about 400 homes.

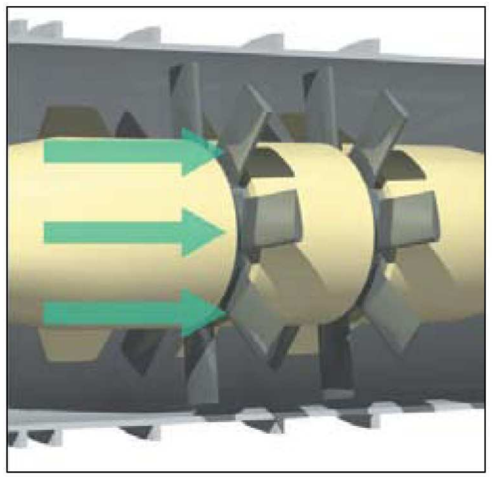
Researchers have developed several mechanisms for capturing wave energy, including tapered-channel systems that funnel waves into a turbine, underwater turbines powered by currents, and float systems that rise and fall on the water's surface, driving pistons that convert the motion into energy. Wavegen chose an oscillating water column approach. Waves rolling into shore push up the water level inside a large, partially submerged concrete chamber built into the shoreline. The rising water forces the air trapped in the chamber through a hole and into the mouth of a turbine. When the waves recede, the falling water level in the chamber sucks air through the turbine in the opposite direction. The key to the system is its use of a so-called Wells turbine, whose blades rotate in the same direction regardless of airflow direction. The spinning turbine drives a generator that produces electricity. Limpet is seen as a key test bed for furthering developments in wave energy technology.

Indeed, most of the progress in wave power is occurring in countries with lots of coastline: Britain, Japan, Australia and New Zealand. In the States, work on the technology slowed with U.S. Department of Energy budget cuts in the 1980s. But ocean-wave energy is still on the radar screen in California, where the California Energy Commission is assessing its viability and San Diego State University is putting together a consortium that could one day bring wave power to American shores. TR

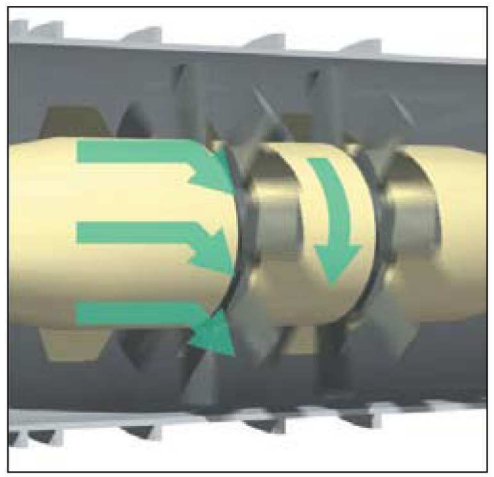
For an animated version of this illustration, go to www.technologyreview.com/visualize



WAVE RISES, AIR RUSHES IN

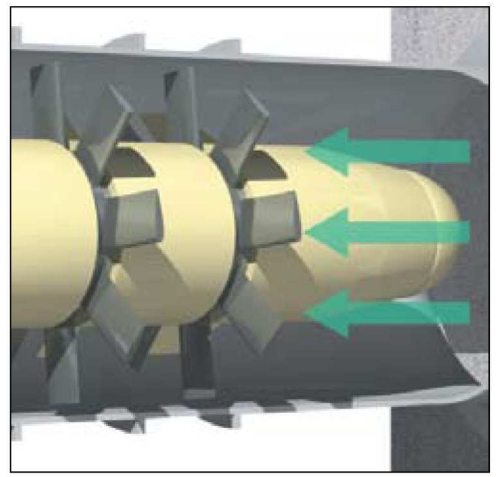


The flow of air into the Wells turbine is perpendicular to the teardrop-shaped blades. But the wind alone does not set the blades in motion. An initial electric current gets them spinning.

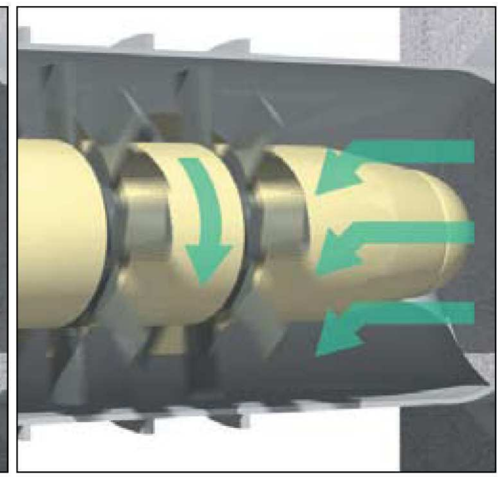


Once in motion, the blades "feel" the air pressing on them at a 45-degree angle. The force is transferred down the teardrop, pressing the blade down to keep the turbine spinning on its own.

WAVE FALLS, AIR RUSHES OUT

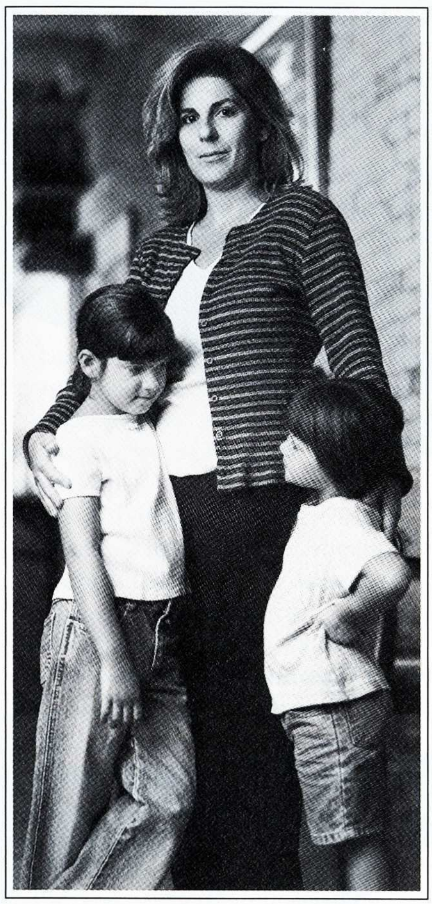


Air flowing out of the turbine in the opposite direction behaves the same way. If the blades were stationary, the air would hit them at a 90-degree angle and they would not spin.



When the blades are in motion, the air being sucked through is directed down the teardrop, spinning the turbine and generating electricity.

Reading is a great way to escape. It helped this family get out of the projects.



To families living in poverty, it sometimes seems there's no way out. And for many of them, poor literacy skills are the source of their own captivity. Today, one in every five people in America would have difficulty understanding these very words. A parent who can't read a job application can't earn a living. A child who fails in school doesn't earn a diploma. Entire generations become trapped in a bleak pattern of underachievement and need. Their only escape is through the classroom door. The National Center for Family Literacy is working to help break the cycle of intergenerational poverty by teaching parents and their children the skills necessary for success. Family members learn to read and write well, to maintain good study habits, to hold a steady job. They learn how to manage a household budget and to plan for the future. We hold out a hand and they learn to pull themselves up. We need a hand as well. You can volunteer to participate in a family literacy program. You can offer someone a job. Or you can simply write out a check. Whatever choice you make, you can be the reason one more family succeeds and poverty fails. Please call the Family Literacy InfoLine at 1-877-FAMLIT-1 or visit www.famlit.org.

NATIONAL CENTER *for* FAMILY LITERACY

OF *TREK* AND TIVO

Gene Roddenberry's *Star Trek*, which first aired in 1966, drew inspiration from a century-old strand of technological utopianism in American science fiction. Writers like *Looking Backward* author Edward Bellamy had long envisioned improvements in communications and transportation as a way out of the economic injustices and blighted environments of the Industrial Revolution and a means toward perfecting society. *Star Trek* was nothing if not optimistic about technology; each week, the captain and crew trusted their lives to the miracles of modern science. True, there were hints of something darker (the uppity computer gods that Kirk disconnected, for instance), but in the end, Scotty and his engineers set things right.

Enterprise, which debuted this fall on UPN as the newest entry in the Star Trek franchise, has a fundamentally different vision. Its crew copes with bleeding-edge technologies: they don't trust the transporter not to scramble their molecular data, the torpedoes miss their targets, the shields are on the fritz and the computers make crappy food. Starfleet is now a paternalistic bureaucracy. In short, the message is, we have seen the future and it doesn't work.

Why the change? In the 1960s, faith in technological progress came easily, since most of the equipment was still in the hands of the guys in the white lab coats at NASA and MIT. And Starfleet embodied the idealism of John F. Kennedy's New Frontier. Today we live, day in and day out, with technologies that have been shipped before being adequately debugged, which can shut themselves down or wipe our e-mail archives without notice. The newer the technology, the less likely it is to do what it promises, and as for getting reliable service, forget about it.

The MIT Media Laboratory still trots out the old technological utopian line with its promises of "things that think"—smart gadgets in the service of humanity. But a lot of the rest of the country fears machines with minds of their own. In our heart of hearts, we assume that any computer that can speak to our vacuum cleaners may also cut off our oxygen supply and shove our pets into the trash compactor when we aren't looking. Twentieth-century literary luminaries James Thurber and Robert Benchley often depicted modern technology as a hostile intruder in our homes. At best, it's a clumsy visitor: I can't help but think of Rube Goldberg when I look at the toppling tower of black boxes (my VCR with its blinking lights, my CD player, my digital recorder, my digital cable box, my surround-sound speakers, various videotapes) next to my television set and alongside the various remotes.

It's hard to take seriously the original *Star Trek*'s technological utopian premise when contemporary devices—some inspired by the series itself, some even used to watch it—are totally unreliable. Improvements in communications technologies, indeed! There are at least three problems. First, the new machines are still buggy when they reach our hands. How many of us have to shout into our cell phones, which often look suspiciously like *Star Trek*'s flip-open communicators, but with a much more limited calling area? Second, the companies that send us these gadgets never quite seem to know how to set up a customer service department equipped to deal with the bugs as they emerge. And then there are the design errors that make you wonder if the machines' engineers had a Vulcan or Klingon customer in mind rather than a human being. Why are the media devices that we mostly use in darkened rooms always black? Why do they put all the useful information—the model number, serial number, even the phone number for customer service—on the bottom of the VCR?

Consider the sad tale of my TiVo digital video recorder, which I bought with the highest optimism that it would transform television as I knew it. I could preprogram it to tape all of my favorite shows; I could watch whatever I wanted, whenever I wanted. In reality, it took Philips six months from the date of purchase to get me a workable unit, six months of dealing with 45-minute service calls, six months of performing silly rituals like wrapping my unit in tinfoil to see if the infrared detector was really working, six months of shipping defective units back and forth since they can't seem to check them out before sending them to dissatisfied customers. I felt totally alone, since so many friends swore by their TiVos, until I visited the company's help page and found that the largest single category of helpful advice was postings by customers who had received more than two nonworking units. And then, no sooner did I get my unit working than my cable company went digital. The two digital boxes have real difficulties communicating with each other and thus will randomly decide to record the wrong program.

In our heart of hearts, we assume that any computer that can speak to our vacuum cleaners may also cut off our oxygen supply and shove our pets into the trash compactor when we aren't looking.

TiVo's other promise was that its intelligent agents would monitor my taste and surprise me with programs they think I want to see—which turned out to be a bit like having the cat drag home a dead mouse. This so-called smart agent, for example, never bothered to ask what languages I speak and so brings me Russian-language soap operas. If it only shipped with a Universal Translator, I'd be in great shape!

So as I sit in my living room wondering whether my TiVo is going to catch the broadcast beams and knowing full well that I am pretty much on my own if problems strike, the more pessimistic vision of technology in *Enterprise* seems about right to me. Just once I'd like to buy a new gizmo and not feel like I had to boldly go where no one has gone before. TR

CRYPTOGRAPHIC ABUNDANCE

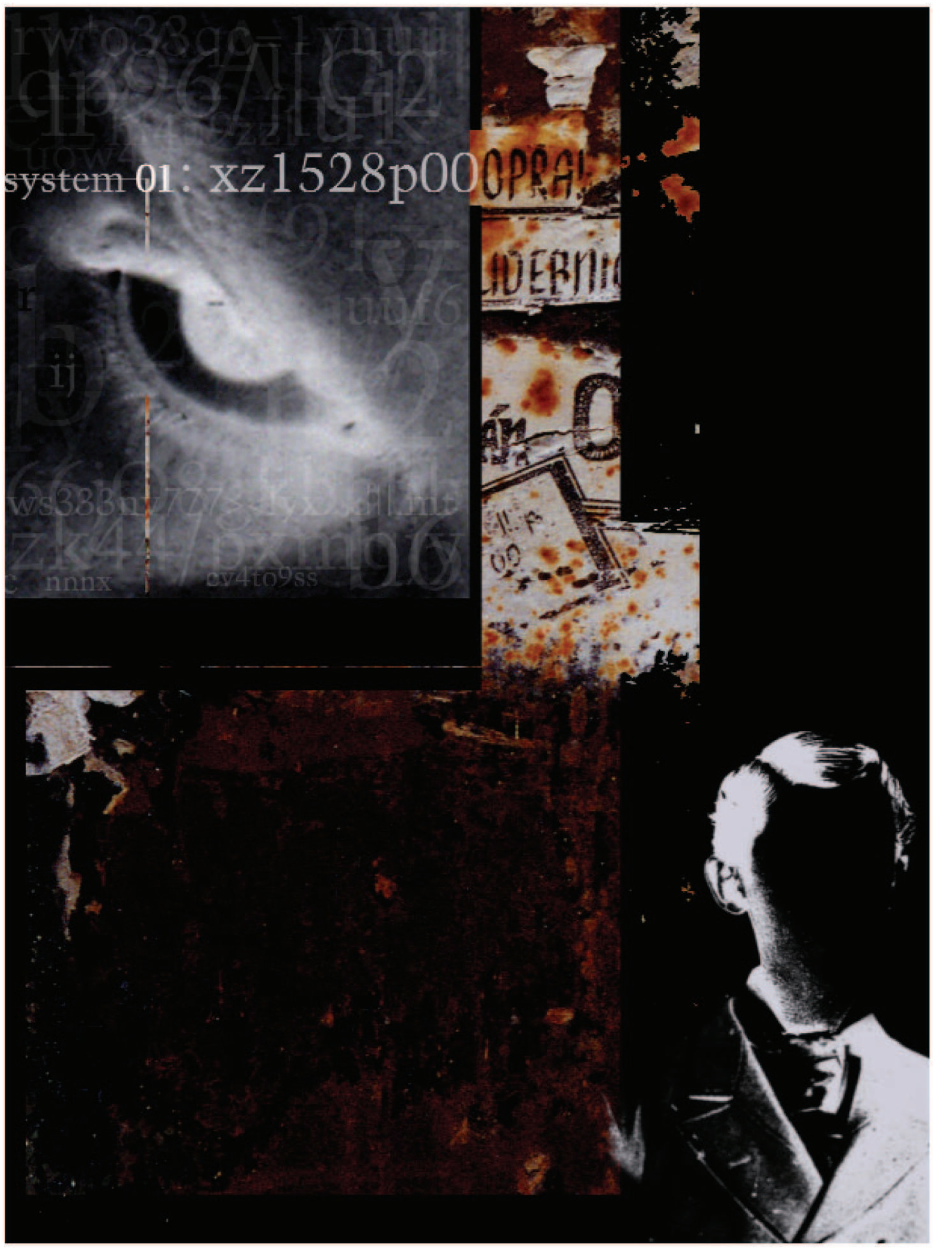
Information can easily be made more secure—if consumers demand it. BY TOM BERSON

My 82-year-old mother never was very good at arithmetic. She now has lost the ability to balance her checkbook. Yet this morning, at the touch of a button on her browser, she performed a fairly sophisticated arithmetic operation on her way to establishing a secure session with the e-commerce site where she orders her medications. This operation is called "modular exponentiation." If Mom knew its nine-syllable name she would have been afraid to push the button. Fortunately, and crucially, the operation is hidden from her, as it is from most of us. It is part of a cryptographic system, a system designed to provide confidential communication.

To Mom's eternal puzzlement, I am a cryptographer, an expert in making and breaking secrets. Cryptography is at least as old as writing. Indeed, before the rise of literacy, writing itself was a form of cryptography. Written messages among literate people could safely be transmitted via illiterate couriers. The spread of literacy led to the invention of ways to obscure the meaning of a message—for example, reordering letters, or substituting some letters for others. Modern cryptographic algorithms still rely on reordering and substitution. But of course, we now use computers to manipulate the symbols.

Knowledge of cryptographic techniques used to belong almost exclusively to governments, which use cryptography to protect political, diplomatic and military secrets against the prying eyes of other governments. Historically, governments took steps to restrict the spread of cryptographic knowledge. Cryptographic activities were conducted in secret departments, some actually called "Black Chambers." Cryptographic texts were suppressed or classified. Knowledge was passed from person to person, from master to apprentice. Trade in cryptographic information or equipment was banned. The field of cryptography was intentionally cloaked in mystery.

In the late 1970s, significant cryptographic knowledge, and the abilities to invent and implement cryptographic systems, spread beyond the black chambers of government into academic and industrial settings. We saw the start of annual research conferences on cryptography and the establishment of an open professional literature on the subject consisting of journals, conference proceedings, textbooks and eventually



BRIAN HUBBLE

Web pages. We also saw some governments, perhaps bowing to the inevitable, reduce their attempts to repress knowledge of cryptography.

One knee-jerk reaction in the aftermath of the September 11 attacks was to call for a ban on the use of cryptography. Even if this were desirable, it would be difficult to achieve—as there are now thousands of competent cryptographers in more than 50 nations. The genie of cryptographic knowledge is out of its chamber.

What do cryptographers today believe about cryptography? Generally, they believe what they have learned through experience: that cryptography is hard to understand, hard to implement correctly and computationally expensive. As a result, system designers have learned to avoid cryptography wherever possible, and to use it only sparingly when it is used at all. This avoidance has led to, among other dysfunctional wonders, e-mail systems that tell everything to everyone and cellular telephones that not only expose conversations but whose device identities can be stolen and misused *(see* "*The Undefended Airwaves,*" TR *September 2001).*

But this view of cryptography is at least a quarter-century out of date. Moore's Law—the rule of thumb that the number of transistors on a chip doubles every 18 months—has delivered a 100,000-fold increase in computational power in the past 25 years. We are therefore rapidly approaching the time when cryptographic operations will be cheap and easy, commonplace and unremarkable. Instead of avoiding or conserving cryptographic operations, designers should now be using them freely.

For example, a new cryptographic algorithm called the Advanced Encryption Standard was adopted in February 2001 as a draft U.S. Federal Information Processing Standard. It's about 4,000,000,000,000,000,000,000 times more secure than its predecessor, the Data Encryption Standard, yet it operates many times faster. Inexpensive chips will be available in 2002 that can execute the new algorithm at multigigabit-per-second rates, fast enough to make fiber-optic links secure. These same chips will be able to perform 10,000 modular exponentiations per second, thereby accelerating e-commerce applications such as the ordering of medications over the Internet.

The sudden abundance of previously scarce cryptographic resources will have profound effects on the ecology of people, systems and information. Abundant cryptography will protect us from identity thieves who exploit access to private information in order to usurp their unsuspecting victims' personae. Similarly, we will be protected from exploitation, blackmail, extortion, gossip and unwanted surveillance, whether from businesses claiming to be "acting in our best interests" or from governments acting extralegally.

Businesses using abundant cryptography will be capable of creating systems that act on our behalf to validate the origin and content of every piece of software we execute, every Web page we read, and every message or telephone call we receive. Say goodbye to spam e-mail and to direct marketing by telephone, unless you like that sort of thing. Abundant cryptography therefore has the potential to help secure time for recreation and refuge, for increased productivity, and for introspection and spiritual growth.

All these things are technically possible today. But despite the feasibility of cheap, easily implemented and abundant cryptography, social and economic obstacles stand between us and these potential benefits. Consumers, be they individuals, businesses or governments, have now been trained by their exposure to poor systems to have low expectations about their security and privacy.

One important problem is that the privacy interests of consumers are not aligned with the economic interests of the companies that provide their information systems. These companies have no incentive to protect their customers' private data. In fact, they have every incentive to collect the data in order to advance their own marketing interests or to sell it to others. The foxes are building the henhouses.

The Ralph Nader of information security has yet to emerge, but I hope to meet him or her soon. Consumer advocacy, coupled with abundant cryptography and better information systems, can lead to a future where information about us as individuals, our private information, will be protected by encryption no matter how it is generated or stored or transmitted. Some argue that this will also protect information about terrorists and is therefore undesirable. I believe that in a society based on law, necessary surveillance of the few can be conducted through the proper operation of law rather than by denying the entire citizenry access to effective self-protection technologies.

Once we've realized that there is no technological barrier between us and the benefits of abundant cryptography, we will revise our expectations upward.

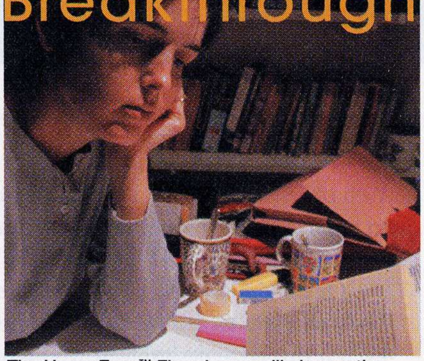
What can you do in the meantime? Educate yourself. Once enough of us realize that there is no technological barrier between us and the benefits I've described, we will naturally revise our expectations about personal privacy and security upward and demand better. When enough of us understand how easy it is to make truly secure systems, and refuse to buy anything that offers us less, we will give companies the economic incentive they currently lack. Refuse to trust the foxes of the world. TR

Tom Berson is a principal scientist at the Xerox Palo Alto Research Center and a past president of the International Association for Cryptologic Research.

Lighting Technology Breakthrough

A floor lamp that spreads sunshine all over a room

The HappyEyes™ Floor Lamp brings the benefits of natural daylight indoors for glare-free lighting that's perfect for a variety of indoor activities.

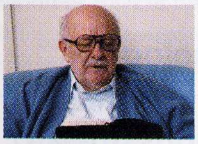


The HappyEyes™ Floor Lamp will change the way you see and feel about your living or work spaces.

Ever since the first human went into a dark cave and built a fire, people have realized the importance of proper indoor lighting. Unfortunately, since Edison invented the light bulb, lighting technology has remained relatively prehistoric. Modern light fixtures do little to combat many symptoms of improper lighting, such as eye strain, dryness or burning. As more and more of us spend longer hours in front of a computer monitor, the results are compounded. And the effects of indoor lighting are not necessarily limited to physical well being. Many people believe that the quantity and quality of light can play a part in one's mood and work performance. Now Verilux®, a leader in healthy lighting since 1956 has developed a better way to bring the positive benefits of natural sunlight indoors.

Use the HappyEyes™ Floor Lamp...

...for hobbies...



...for reading...

...for working...

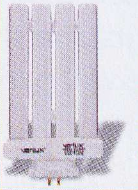
...and when you need a good source of light for close-up tasks.

The HappyEyes™ Floor Lamp will change the way you see and feel about your living or work spaces. Studies show that sunshine can lift your mood and your energy levels, but as we all know the sun, unfortunately, does not always shine. So to bring the benefits of natural daylight indoors, Verilux, The Healthy Lighting Company™, created the HappyEyes Floor Lamp that simulates the balanced spectrum of daylight. You will see with more comfort and ease as this lamp provides sharp visibility for close tasks and reduces eyestrain.

You don't need the Sun to get the natural benefits of daylight

- Replicates the balanced spectrum of natural sunlight
- See with comfort and ease
- Creates natural, glare-free light
- Provides sharp visibility
- Uplifting, cheerful and bright
- Flexible gooseneck design
- Instant-on, flicker-free light

Technology revolutionizes the light bulb



- 5,000 hours bulb life
- Energy efficient
- Shows true colors
- Two light levels

Its 27-Watt compact fluorescent bulb is the equivalent to a 150-Watt ordinary light bulb. This makes it perfect for activities such as reading, writing, sewing and needlepoint, and especially for aging eyes. For artists, the HappyEyes Floor Lamp can bring a source of natural light into a studio, and show the true colors of a work. This lamp has a flexible gooseneck design for maximum efficiency and two levels of light, with an "Instant On" switch that is flicker-free. The high fidelity electronics, ergonomically correct design, and bulb that lasts five times longer than an ordinary bulb makes this product a must-see.

This light can change the way you live and work

I love it! Reading is so much easier on my eyes. It's also great for doing crafts. The lamp's light weight allows me to bring it anywhere.
—*Karen R. CA*

It really brightens up my office, Thank you.
—*Jan L. GA*

I use my computer all the time and WOW what a difference. I just put it up and I can see!
—*Kathy N. CA*

It is really nice and eliminates the glare!
—*Nita P. CA*

It is a nice sunny product for a windowless office.
—*Edith L. NJ*

Dozens of testimonials on file
Results not typical

Try this risk-free, manufacturer direct special offer. The HappyEyes Floor Lamp comes with a one-year manufacturer's limited warranty and TechnoScout's exclusive risk-free home trial. If you're not fully satisfied, return it within 30 days for a complete "No Questions Asked" refund.

HappyEyes™ Floor Lamp
ZZ-1777 . . . . **$129.95** $15.95 S&H
Please mention source code 21777

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***The Lund Institute of Technology** – LTH - is one of Sweden's largest technical universities with research and postgraduate teaching in 90 subjects within mathematics, the natural sciences, engineering, social planning and design. The institute provides both Bachelor's and Master's programmes, as well as programmes in Fire Safety Engineering, Architecture and Industrial Design. The total number of students studying at LTH is about 800 postgraduates and 5,000 undergraduates, at Lund and Helsingborg.*
The Institute forms the Engineering Faculty of Lund University in southern Sweden, which has approx. 32,000 students and offers a wide range of programmes, including the arts, law, economics, social sciences and medicine. Lund University is part of the Öresund University, along with ten other institutes of higher education in Skåne and Sjælland, with 120,000 students. Lund University has a strong international profile, collaborating with hundreds of universities and research centres all over the world.

As part of the university's new focusing on entrepreneurship and innovation, a new position has been established – The Ruben Rausing Chair of Innovation Management – located at LTH. The professorship is sponsored by the Ruben Rausing Fund for Research, New Enterprises and Innovations. A great number of higher education and university facilities are located within the Öresund Region. Together with a dynamic business climate this provide an excellent base for research and education on entrepreneurship and innovation. Lund University intends to be the leading knowledge-centre in Scandinavia within these disciplines. The professor in innovation management will co-operate with the recently appointed professor in entrepreneurship, at the School of Economics and Management, as well as with the professor in R&D organization and policy, at the Research Policy Institute.

Lund University welcomes applications for

THE RUBEN RAUSING CHAIR OF INNOVATION MANAGEMENT

Reference no.: 1660

Description of the subject

Innovation management deals with the conditions, methods and management for bringing ideas into implementation. The subject has an all-embracing approach including products and processes as a driving force for the development of new products and services. In this approach the interaction between people, technology and the organisation should be considered.

The subject also includes the interfaces between spontaneous social processes as well as methods for knowledge and business management. The development of technology-based innovations will be studied, by utilizing the great potentiality at hand, at LTH and other places.

Information on duties and assessment criteria is to be found at http://www.lth.se, Job opportunities.

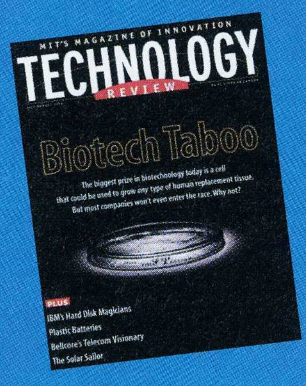
The majority of professors at the Lund Institute of Technology are men. The University therefore welcomes female applicants for the position.

Inquiries regarding this position may be addressed to Professor Bengt Sundén, chairman of the appointment committee, +46 46 222 86 05, Bengt.Sunden@vok.lth.se, or Professor Gunilla Jönson, department of design sciences, +46 46 222 94 44, Gunilla.Jonson@tlog.lth.se. Inquiries regarding terms of employment may be addressed to LTHs personnel director, Sonja Meiby, +46 46 222 71 17, Sonja.Meiby@kansli.lth.se.

Applications are to be submitted in English and should be formulated in accordance with the appropriate instructions, see http://www.lth.se, Job opportunities.

Applications, with reference number indicated, should be addressed to the Rector of Lund University and must have reached the desk of the University Registrar, P.O.Box 117, SE-221 00 Lund, Sweden, at latest on **Wednesday 16 January, 2002.**

LUNDS TEKNISKA HÖGSKOLA
Lunds universitet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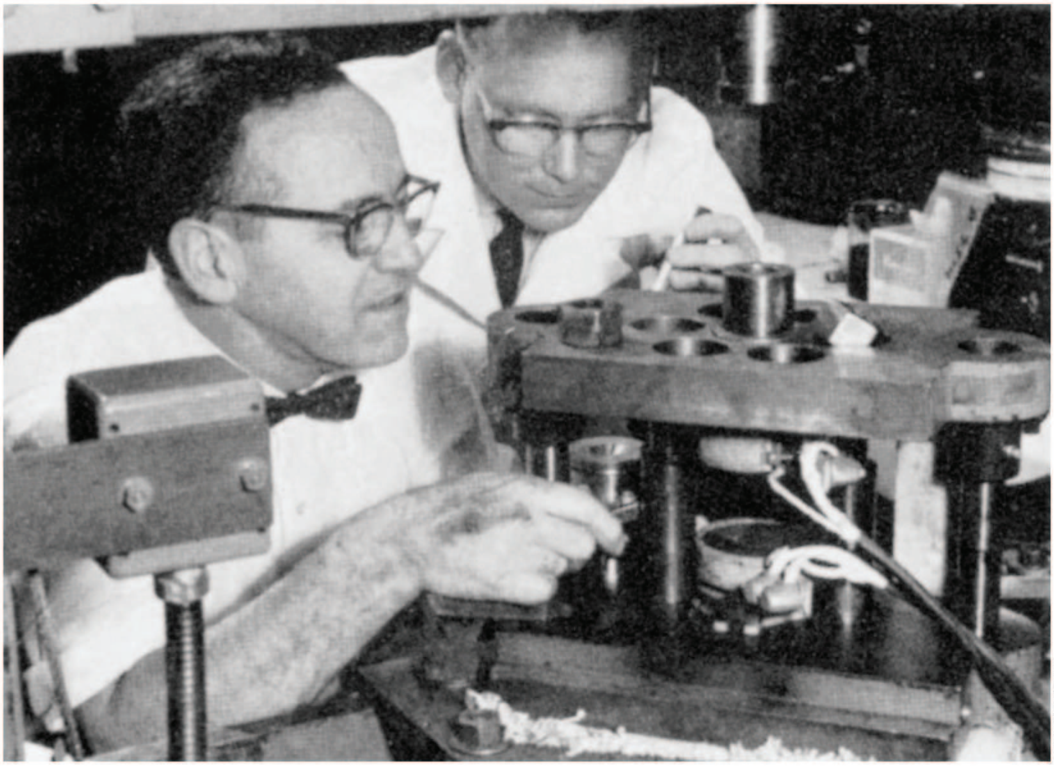

COURTESY OF DUPONT

ENGINEER'S ART

Nathaniel Wyeth sculpted plastic into a better soda bottle

Many families have a black sheep, someone who takes off on his or her own path rather than following family tradition. But few black sheep make as enduring—if a tad mundane—a contribution to society as Nathaniel Wyeth did with his invention of the plastic soda bottle.

Born into what many critics consider America's foremost artistic family, Nathaniel Wyeth—named at birth Newell Convers Wyeth after his famous father—showed an early aptitude for engineering. In fact, his technical bent was so obvious almost from the start that at the age of three he was renamed after the senior N.C.'s brother Nathaniel, an engineer. While the rest of the Wyeth kids—younger brother Andrew and three sisters—went into art or music, Nathaniel studied engineering.

Wyeth spent most of his career at DuPont, working on various mechanical devices. One day in 1967, he wondered out loud why plastic wasn't used for soda bottles. A colleague replied that plastic wasn't strong enough; the carbonation would make the bottles expand and explode. Ever the tinkerer, Wyeth went out and bought a plastic bottle of detergent. He took it home, replaced the soap with ginger ale and left the bottle in the refrigerator. Sure enough, the container ballooned overnight and lodged itself tightly between the refrigerator shelves. So Wyeth began his quest to develop a plastic strong enough to keep carbonated beverages in check.

He knew that stretching nylon threads actually strengthens them, since it forces their molecules to align; to fortify plastic for bottles, however, he needed to line the molecules up in two dimensions rather than just one. His solution was a mold that resembled a test tube with screw threads—but the threads crisscrossed one another rather than running in a single spiral. When he pushed polypropylene through the mold, its molecules lined up in two dimensions, making the plastic strong enough to hold soda without deforming. But only after experimenting with thousands of polymers did Wyeth *(above left)* find one that gave him clear, light bottles and contained the carbonation without expanding.

In 1973, Wyeth filed for a patent on polyethylene terephthalate, or PET, soda bottles. Today billions of the bottles are produced each year in the United States, and they have become one of the most recycled household products. Polyester from recycled PET bottles goes into carpets, fabric, insulation and stuffing for furniture and sleeping bags. TR

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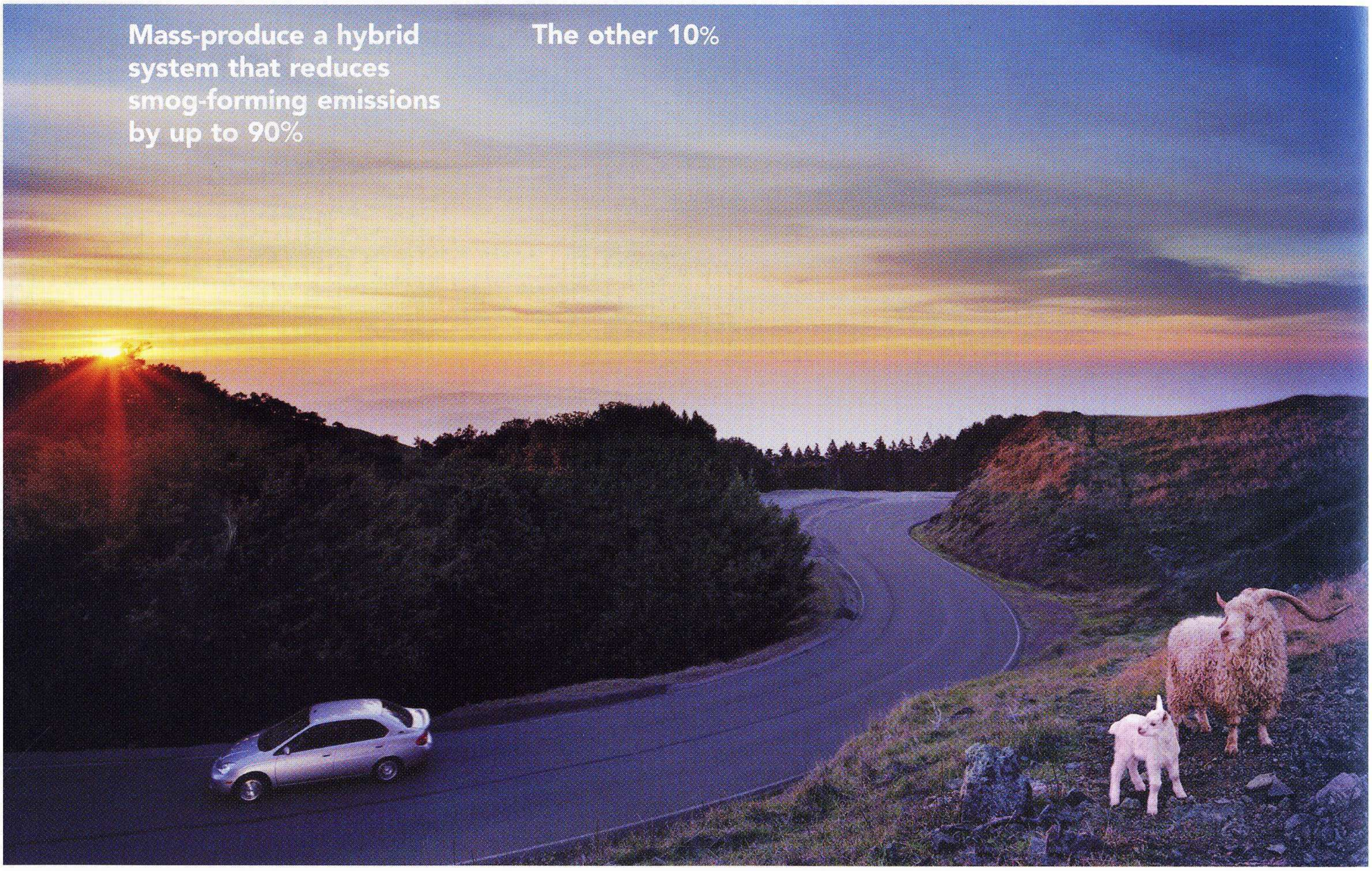
TODAY **TOMORROW** **TOYOTA**



In 1997, Toyota was the first car company in the world to mass-produce a hybrid vehicle. By combining gasoline and electric power, the Prius reduces smog-forming emissions*, cuts gas consumption in half, and, in short, has revolutionized the way cars affect our environment.

Even so, we're not resting on our laurels. The Toyota Hybrid System is being further refined, to make it cleaner and more efficient. And we're continuing to search for even greener forms of transportation.

Our hydrogen-powered fuel cell hybrid SUV is now being road-tested. Its only emission is pure water. Beyond that, who knows. But no matter what alternatives are discovered in the future, they won't be found overnight. They'll be the result of 90% perspiration. And 10% inspiration.

www.toyota.com/tomorrow

*Based on measurements of hydrocarbons and oxides of nitrogen. Compared to the average car.